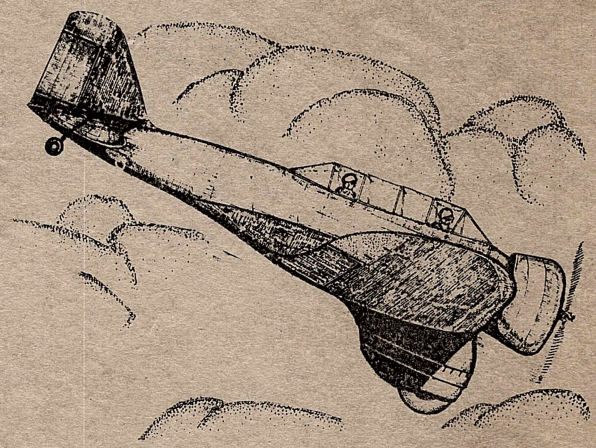
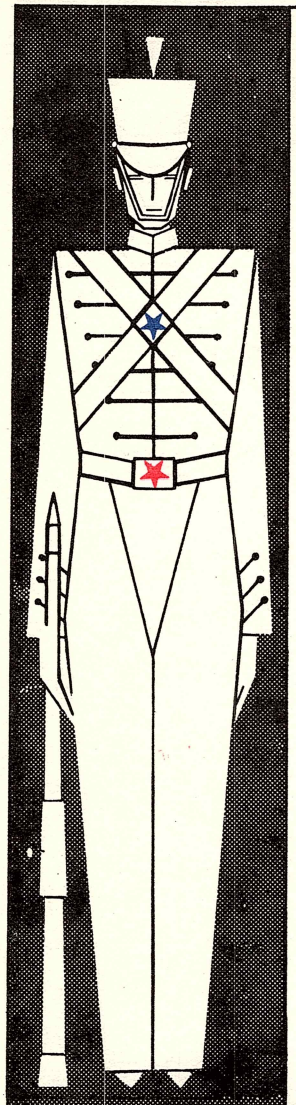
METAL AIRCRAFT

DESIGN AND CONSTRUCTION



BY
WILLIS L. NYE



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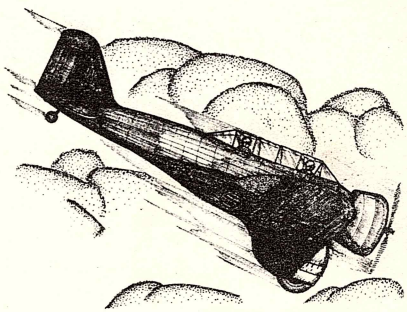

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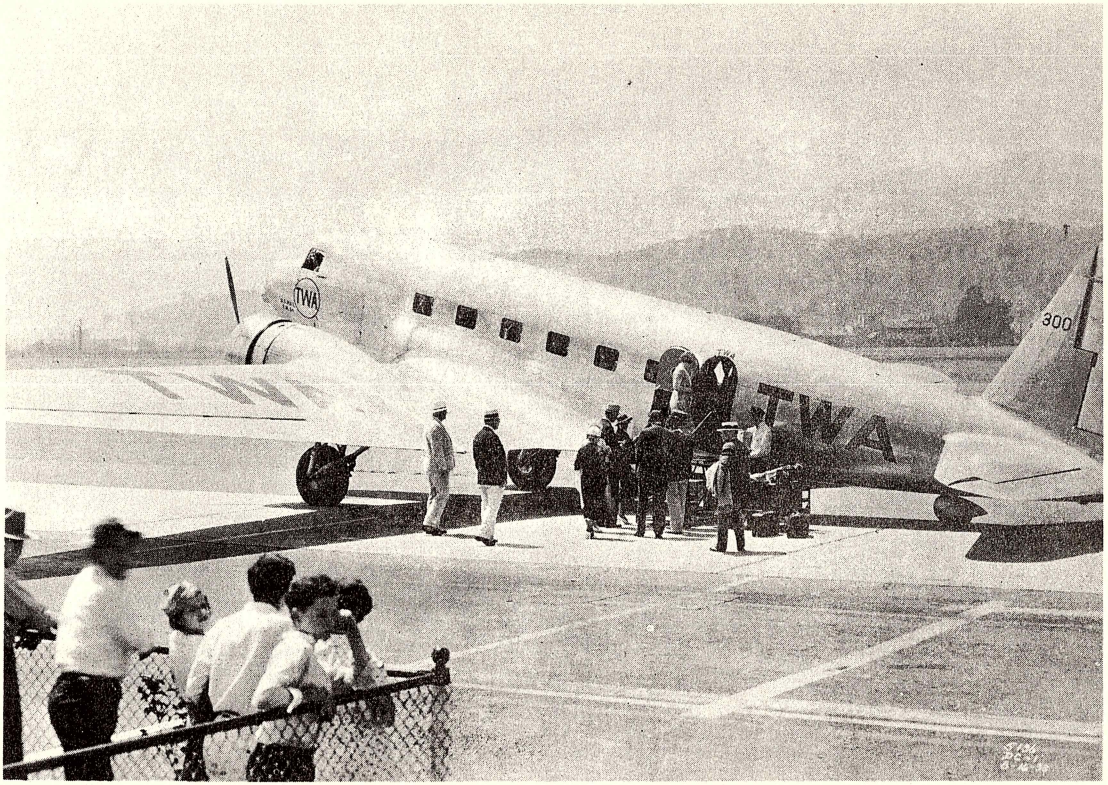

THE DOUGLAS DC-1 AIRLINER

An all metal airplane of extremely high performance and efficiency.

PREFACE

In presenting this publication dealing with the methods of construction, design, and production of metal aircraft, the author has striven to present this rather complex topic in an elementary and informative way for the student, the draughtsman, and the shop mechanic.

The rapid evolution of the metal aircraft, as exemplified by the latest transport planes,has necessitated practically a complete change in production methods,technique, design, and type. Casually speaking, there has been a very pronounced lack of good technical data available for dissemination among the industry. This latter condition has been imposed both by the times and other vital factors, and the secrecy required by the government for military contractors. The entire desire of the author has been to fill this gap so that the tyro and novice would have a reference text when encountering the problems imposed by modern production methods.

At one time the only persons who built airplanes were the men who flew them. This condition has given away to the exigencies of highly specialized design requirements. Modern metal aircraft and shell structures require a thorough and complete knowledge of working light gauge metal with maximum efficiency. For the designer this has meant scrapping of the old ideas and acquiring a fundamental knowledge of the strength, the weight,and the production requirements imposed by the stringent limitations of factory costs.

This publication has endeavored to cover the field of metal construction as practiced in the U.S.A. and by the better foreign manufacturers. The design technical information is herein given to enable the student to derive a working knowledge of the fundamental problems. In the scope of this text no attempt has been made to cover subsidiary structures, such as landing gears, struts, fittings, and seaplane floats or hull construction. Those subjects mentioned are each in themselves very complex. The text does not aim to specialize in any one subject. Instead a general picture of

the practices and methods, the technique and ways of manufacture, along with examples of metal elements, are drawn in such a way that to the enthusiastic exponent of metal aircraft they will be intelligible. As a drafting reference the proportions of the spar sections are such that, as a general element, they are correct for reference.

The various chapters are arranged in a manner of progression and the instructor may use the text as a syllabus due to this method of compilation. Obviously every example of metal construction could not be shown because of limited space. Nevertheless the basic construction of the important members of shell structures have been covered so that a panorama of current metal practice in the U.S.A. has been presented.

As the important thing to be brought home to the reader, Chapter Three endeavors to explain the technique of the fabrication of light shell structures. It points out the truth that to build these delicate structures specialization in sheet metal work and allied arts is necessary. Each part of the structure requires intense specialization and experience in the particular phase of the work.

The author expresses his appreciation to the following persons and firms who generously allowed use of their time, experience, and their data: Mr. Fred J. Turner, formerly of the experimental department of Douglas Aircraft Co., Santa Monica, Calif.; Mr. Grosvenor Francis of San Francisco, Calif.; Mr. Hal Ryder of Pacific Metals Co., San Francisco, Calif.; Mr. William Duck of Duck Air Services, Oakland, Calif.; The Aluminum Co. of America.; The Chicago Pneumatic Tool Co., and Pacific Metals Co.

WILLIS L. NYE

July 15, 1935.

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Elementary Airplane Structural Analysis by Graphic Methods, by JAMES P. EAMES, Aviation Press, San Francisco, 1938; 180 pages, $3.00. (Loose leaf lithographed.)

This book is a simplified text dealing with the methods of stress analysis of airplane structures within reach of the aeronautical engineering student and the aircraft factory draftsman.

The first chapter is a review of elementary graphics and mechanics. There follow chapters on the characteristics of wood and metal airplane members, airworthiness requirements, fuselage structural analysis, wing truss structural analysis, and structural analysis of control members.

Appendices treat various specialized subjects, such as stagger loads, the equation of three moments, the method of least work.

A typical examination and a questionnaire are given at the end along with a glossary of terms.

The selected illustrative design problem which is projected throughout the latter chapters treat features of the analysis of a framed biplane structure. The biplane arrangement was selected as it represents a more complicated structure than the monoplane type, and the student with a knowledge of the principles can easily pass to the monoplane analysis.

The many figures are excellent and the description of the methods is well done. Although the treatment is not always rigorous the scope and general methods are given.

Practical Aeronautical Engineering, by WILLIS L. NYE, Aviation Press, San Francisco, 1938; 187 pages, $4.00. (Loose-leaf lithographed.)

This book is designed to "serve as an intermediate text for the student engineer actively interested in modern airplane construction." It is intended as a continuation for the student who has digested "the Cadet System" by Leslie Thorpe (same publisher.) The subjects covered include aircraft design procedure, airfoil data, aerodynamic factors in design, parasite resistance data, stability, control and control surfaces, propellers, aircraft engineers and installation problems, landing gears, performance calculations, high performance aircraft, economics of aircraft structure, and weight control. There are 164 excellent figures and the data compiled in 145 tables should find ready use.

Book reviews

Aviation Service and Maintenance, by James G. Thompson, Size, 9 by 11 inches. Cardboard, 161 pages. Illustrated, $3.00. A Cadet Series Publication, Aviation Press, 580 Market Street, San Francisco, Calif.

The "Aviation Service and Maintenance" articles which have appeared in **Western Flying** for the past seven years form the basis of the latest aviation book, published under the same title in response to popular demand from the followers of this long series of articles.

Complete revisions of all published service articles of the author, James G. Thompson, have been included as part of this 150,000 word volume, together with extensive additions of entirely new material, to form a complete text on practical aviation mechanics. It can truthfully be said that the larger portion of the information in this book has not been available anywhere before, while most of the remainder has been scattered through countless engine and airplane instruction manuals buried deep in a mass of irrelevant material.

Written to augment, rather than to supplant the manuals of engine and airplane manufacturers, this book gives in condensed form the technical information needed for service and maintenance operations pertaining to specific popular engines and airplanes, and contains an additional wealth of practical service and maintenance information.

The Yonkers Record, Saturday, January 28, 1939

NEW TECHNICAL BOOKS

METAL AIRCRAFT; DESIGN AND CONSTRUCTION, by Willis L. Nye; Aviation Press, San Francisco, Calif.—Nye's new book takes cognizance of the trend toward all-metal construction in aviation, and treats upon it not only exhaustively, but in a practical manner to make for understanding. He discusses the rlative merits of each type of construction, tooling and production methods used in the U. S., minor metal airplane parts, metal weights, etc. Almost 250 graphic illustrations enhance the volume further.

AIRCRAFT MANUAL FOR INSPECTION, MAINTENANCE AND REPAIR, by Ensign Jack Lincke, Aviation Press, San Francisco, Calif.—This big book offers complete instructions for taking care of sea, land and amphibians of 1, 2 and 3 engines, including all aircraft and engine equipment. Over 125 drawings and photos illustrate the salient points of the latest type airplanes and engines, and Lincke has included as well a new method of fabric repair and prevention of explosion in welding fuel tanks.

THE NEW CADET SYSTEM OF GROUND SCHOOL TRAINING, by Lt. Leslie Thorpe; Aviation Press, San Francisco, Calif.—This new and considerably revised edition of a now well-known work is still the best available for the student of aeronautics. Lt. Thorpe treats to the smallest detail on flight, construction, engines, navigation and other technical and mathematical matters. The work, like the others, is illustrated and priced moderately. It should be noted also by the public and high school teacher as well as student.

CHAPTER I

EVOLUTION METAL AIRCRAFT CONSTRUCTION IN U. S. A.

WARTIME DEVELOPMENT.

Since the inception of the heavier-than-air craft, the desirability of the metal airplane structure has been uppermost in the mind of the aeronautical engineer. The benefits of metal structures are obvious.

Wood at its best is a material of variable properties. Metal on the other hand, being a manufactured material, can have its properties determined within close limits. To offset the inherent weakness of wood a larger margin of safety must be employed and this makes for overweight and excess material. Wood is mostly unsuitable for tension members and at best its use in compression is questionable. The other bad features of moisture absorption and the dependence on glued joints relegates its use to the background.

Metals lend themselves admirably to modern production methods, the ease of replacing of parts, the accuracy of stress analysis possible, and the durability and high fatigue strength, has made the metal structure very appealing to the engineer.

The first successful metal aircraft was produced by the founder of the Blackburn Aircraft, Ltd. in England. This monoplane was of the orthodox type, wire braced, using wings of metal skeleton covered with high tensile strip steel all riveted together. The fuselage was a frame affair covered likewise. This plane marked the turning point in structural design.

Although the technique of all metal riveted aircraft was vigorously developed by the Junkers interests during the war in Germany, little research work had been undertaken elsewhere. The stick and wire type predominated with a few attempts at metal structures mainly of experimental nature. On the other hand the Germans developed the manufacture of suitable aluminum light alloys and the welded steel tubing fuselage. Whether the lack of suitable wooden airplane timber foisted the use of the metal structure onto the German Government is hard to say. However their contributions to the art were noteworthy and have stood the test of time. The only notable efforts elsewhere were undertaken by the Breguet firm in France and the Bristol organization in England.

EARLY AMERICAN PROTOTYPES

Although several attempts by private individuals were made to build and perfect all-metal aircraft, none of this type were incorporated in the American wartime aircraft program. In the latter part of 1918, the Cairns Observation Biplane was produced using a composite metal and fabric structure.

The Cairns biplane represented a distinct advance in the matter of metal structures. It utilized a sheet steel monocoque fuselage with a metal wing structure covered with fabric. It may be considered as the prototype of our metal aircraft such as we know it today.

In postwar commercial aviation specimens of European contemporaries presented their appearance on the American market, which at that time was glutted with the stick and wire construction training planes. The Junkers made its advent into the field, and the benefits of metal aircraft being desirable in the mail service, the Post Office contracted for a limited number and tested them out under service conditions. All this brought home the picture to the American aviation industry that the logical trend was to metal structures. The transition must necessarily be slow and over a period of years mainly due to lack of technique and the availability of suitable raw materials. Among the early pioneers in this field was the Hall Aluminum Aircraft Company, which pioneered and fostered the development of metal aircraft of aluminum construction.

The fundamental reason for the structural difficulties encountered in metal airplane structures was the lack of suitable alloys, technique of heat treatment, fabrication inexperience, and cost. From time to time the Army and the Navy purchased outstanding metal aircraft, but the development was slow. However once the availability of the raw materials was assured and the knowledge of working the same, the development has progressed to the point where American construction methods are on a par with that of European contemporaries, and better in many instances.

ADVENT OF COMPOSITE STRUCTURES

The gradual transition to the metal structure has not been of rapid rate. The period of transition has been forestalled by the scarcity of sound engineering data and the method of economical production. The intermediate step was the composite structure as we know it in commercial designs.

Since the post war period there have been many examples of composite construction[1] planes more or less built along the orthodox line of using a fabric cover with a welded steel tubular fuselage structure with wooden wing framework. The next step was the use of a frame riveted dural structure for the fuselage and pressed dural wing rib with wooden spars, covered with fabric. This form of construction will find considerable use in the manufacture of economical commercial aircraft.

The Sikorsky organization was among the first to use the aluminum alloys extensively in the structural parts of their aircraft. The Hall organization pioneered aluminum shapes and production methods and riveting equipment and licensed them on a royalty basis, thus speeding up the development by other corporations in the same field.

The Curtiss Company pioneered composite construction in their early commercial planes during the boom years and also the development of the riveted dural frame structure in military aircraft. Their wing construction, until recent time, has been the standard wooden spar and pressed dural rib.

The Boeing organization utilized welded steel fuselages with wooden wings and then was among the first to perfect riveted square tubular dural fuselages as well as dural wing structures covered, however, with fabric.

1. The term composite construction refers to mixed aircraft materials in one structure, such as wooden wing structures, fabric covering, and welded steel tubular fuselage.

The Fokker Company was directly responsible for the widespread use of the welded tubular steel fuselage with a wooden cantilever wing. This composite construction has survived the test of time.

The above does not by any means sum up the complete list of concerns who contributed to the gradual development of the all-metal aircraft. The Consolidated Company developed all-metal observation planes in large numbers, using a fabric wing that has proven ideal in all ways. Their metal fuselage was corrugated with stringers and bulkheads and has survived the test of time.

The Ford Company produced several types of ships, all incorporating the ideas of William B. Stout, that have proven extremely durable. These planes were built of Alclad dural with a frame structure and a corrugated covering. They will remain in use for many years. Thus is shown the desirability of the all-metal airplane to be justified, although costly.

COMPOSITE AND ALL-METAL STRUCTURES

As mentioned previously, the reason for composite structures were manifold. There are several basic reasons from the structural standpoint for composite structures. Weight inspection requirements, accessibility, replacement, maintenance, all influence the type of structure. On the basis of weight per square foot the composite wing is the lightest and the cheapest to construct. This construction is the simplest in contrast to the ramifications of the metal wing as we know it today.

The subject of inspection is important. While the engineering ideal is all-metal, inspection of the interior of the all-metal wing is nearly impossible. Unless the covering is stripped off, fatigue[2] cannot be detected. Any metal structure under the influence of variable loads and vibrations and high momentary stresses is subject to fatigue, especially to a high localization of loads.

Anyway one may look at it, pay load is a measure of efficiency; hence on large span aircraft all-metal, unless it is a very light structure, is apt to seriously cut into the pay load requirements. For that reason, many large aircraft are using a part fabric wing and control areas. No matter what may be said or done about it the fabric covered wing, with an internal spar system for the strength, is the lightest for the best strength to weight ratio.

Fabrication cost on an all-metal plane is costly. Metal working requires skilled labor while on the other hand the composite construction can be built excellently with semi-skilled labor. The lasting qualities of metal, when protected from the corrosive effects, makes it attractive since fabric has to be renewed at least once every two years.

SERVICING AND CONSTRUCTION COSTS

Servicing cost is always an item to consider in the light of maintenance expenditures. On large airlines where a large ground crew is employed and the facilities available, the servicing costs of all-metal aircraft is not as important as it is to the private owner with limited

2. Fatigue is used to denote breaking down of the physical strength of the metal. This may occur by lowering the elastic modulus, crystallization, gradual reduction of the strength characteristics by vibration, or localized stresses.

means. Any form of wing needs habitual inspection for safety, both inside and outside, and must be repaired if deteriorated. Hence the appeal for the composite wing on the basis of cheapness in the private owner class.

On the other hand the airlines with unlimited facilities and where extreme durability is required, makes the all-metal airplane ideal, because the cost and servicing, when considered here, are secondary.

The trend of military developments lie in the direction of all metal covered structures. From service and construction standpoints, the type is ideal. In wartime, however, under field service conditions, the all-metal aircraft for repairs to the structure will require a trained sheet metal worker. On a composite structure a semi-skilled workman can effect most repairs successfully.

The attractiveness of all-metal construction from all military angles is ideal. For quick repairing, however, faster methods will have to be perfected and herein lies the ingenuity of the designer. The R.A.F. has not utilized the all-metal shell type of structure extensively because of the highly trained personnel required for repairs. Therefore the composite type using a fabric cover has been the standard.

Under severe conditions of exposure the superiority of the all-metal airplane is apparent. Fabric covered planes suffer severely unless protected from the elements under wartime conditions. Hence the disappearance of the fabric structure for tactical use.

In line with the development of all metal structures comes the question of costs. At present, because of the specialized tooling up costs, the metal shell structure has been higher than a corresponding composite structure. This is offset by the better durability and efficiency of the all-metal structure and is demonstrated by the performance of the latest transport planes. The highly specialized tools for building the light metal structures have required much development expense. With increased production assured the trend of costs will be downward.

Aircraft structures of dural, until the advent of suitable welding processes for light gauge metals, will depend on the use of the riveted joint for holding the component parts together. Riveting in any form is expensive, because of the double labor usually required and the greater time to rivet a given piece of work. Granted that riveting is expensive, yet until the present time there has been no competitive type of construction that has attained the results exemplified by the Douglas, Northrop, and Vultee air transports.

Until recent years there has been little quantity production of metal aircraft on a large scale. The larger volume assured in recent years undoubtedly will soon make the labor cost compare favorably with a composite type of structure. As yet the composite type of structure has not equaled the dead weight pay load attainable with the multicellular all-metal aircraft.

The initial cost of engineering all-metal aircraft has done much to increase the original cost of the metal airplane. The large amount of drafting time, pattern making, mockups[3] and what not, require skilled technical labor in large numbers. For instance a large plane requires

3. The term mockup refers to a full size reproduction of the airplane fuselage or nacelle out of wood. The mockup is used as a guide in laying out the patterns for the exterior covering.

upwards to 100,000 rivets of various sizes to be driven and fitted. Each sheet requires a pattern and a system of identification.

Servicing has many angles that also affect cost. The advent of extreme streamlining has not, as a general rule, decreased the servicing costs on the ground. For instance, in repairs to the wing, if all-metal and of fair proportions, this means a "factory" job of repair in the hangar. With riveted structures, to repair the internal structure means removing the skin, and its various complications.

To offset the inherent increased expense, metal structures when properly constructed stand considerably more abuse than the fabric covered structures. Fabric is always a source of constant repair in hard use. In handling in the hangar, fabric planes are always subject to damage whereas the all-metal structure suffers but little in hard usage.

All cowling, fillets, cover plates, and fairings, while ideal from the aerodynamic standpoint, are sometimes an item of additional cost from the servicing angle. The ability of the designer or manufacturer to develop quick detachable devices for these accessories has not always resulted in the most economical way of ground servicing and the time to do the same.

As an example: The full wheel boot is extremely desirable from the aerodynamic angle of drag reduction for the tire and wheel. On the other hand if it takes considerable time to remove the boot to service the brakes, the bearings, and tire, it is not economical from the servicing angle. The partly exposed boot of the Curtiss type seems a happy compromise. This applies to planes in constant commercial service where the more a plane can be kept in the air the greater the increase in revenue for the air line. A happy compromise in the minor servicing items should always be considered, since dollars and cents count as much in the operation of a successful air line as good piloting or good aircraft.

Another item to consider is the multiplicity and the ease of replacement of worn or injured parts. Somehow this item has been overlooked in the mere contentment that an airplane flew. All parts should be easily accessible and removed easily and at the same time easy to obtain for replacement from the factory. A minimum of parts is desirable. As an example: Most wheel drums and the braking system are in rights and lefts. On the Northrop, by reason of the particular kind of landing gear utilized, 2 right hand type of wheels may be used, and this cuts the amount of spare parts to a minimum. A number of items such as this makes for economy. Herein lies the ingenuity for the designer to incorporate in the structure.

CHAPTER II

AIRCRAFT CONSTRUCTION MATERIALS

ALUMINUM

Aluminum[4], because of its high strength to weight ratio, is the ideal metal for aircraft use when properly manufactured. The advent of the heat treating[5] of aluminum has greatly increased the strength and the workability to structures requiring great strength.

The properties of pure aluminum possess such features that if the material was used in this form it would be unsuitable. By a slight addition of other elements forming an alloy, resistance to corrosive effects, high fatigue strength, and workability are assured. In the alloy form aluminum is termed "dural", and it is to this name that the aluminum alloys are commonly known.

The Aluminum Company of America has conducted researches extensively to bring the material to the high state of perfection it is today. The product is a very superior one, being adaptable with certain mofidications to all uses in the aircraft industry, and in some cases to be a serious competitor to mild steel in strength. Aside from development of the material itself vast contributions to the method of working have emanated from this organization without which the development would have been hampered.

Commercially pure aluminum has a strength in tension of one fourth that of mild steel. The material can be easily spun, drawn, rolled, and formed by ordinary methods. When alloyed with other suitable elements the degree of workability can be increased, and the same applies to the casting. The harder and stronger aluminum is the more difficult to work and form. For the various aircraft uses various alloys have been developed suitable for the many needs. Although the cost per pound is higher than ordinarily found in raw materials, when taken on a basis of a weight relation it is very economical.

The following table is a comparison of the weight of aluminum to ordinary aircraft materials.

MATERIAL	TENSILE STRENGTH	WT. CUBIC FOOT	COMPRESSION STRENGTH
Spruce	6,000 lbs.	29	4,500
Aluminum	36,000 lbs.	168	16,000
Steel	100,000 lbs.	487	50,000

Dural alloys are available in two forms. In one, the alloys produced are suited for various hardness and temper by cold rolling, and, in the other form, by heat treatment and aging the same.

4. The term aluminum refers to the various alloys and dural as used here.

5. Heat treating is heating the metal part to a predetermined temperature in a special furnace to increase the strength characteristics.

A great many shapes are available in rolled form and many from the sheet stock are heat treated to the pre-requisite strength.

The alloys and grades of aluminum and dural have various designations. The three common alloys are the least costly and the rest are the special alloys manufactured for specialized requirements.

ALLOY	COMPOSITION
2S	Natural aluminum
3S	" "
4S	" "
14S	Copper, Silicon, Manganese, Magnesium
17S & 17SRT	" "
A17S	" "
B17S	" "
C17S	" "
18S	" Silicon Manganese
24S & 24SRT	" " Magnesium
25S	" " "

The above table gives the relation of the alloyed elements used in the more common dural alloys. At no time does the amount of extraneous alloy exceed 7 percent. The weights average about one tenth per pound per cubic inch. This table applies to the wrought alloys.

Dural alloys may be sand casted or die casted. In either form it has excellent properties although correct technique is required to get good results.

The dural alloy 24SRT is by far the strongest of the more widely used alloys. The yield per square inch in pounds exceeds 53,000, with an ultimate strength of 62,000 pounds and a very small percentage in elongation. This alloy has a Brinnel hardness of 116 and a shearing strength of 39,000 pounds. The fatigue limit is among the highest of the various alloys.

Sheet stock dural is available in the various alloys and hardnesses in standard widths and lengths. The grade and temper[6] are denoted by the designation. The more commonly used sheet stock for non-structural purposes takes the following:

DESIGNATION	TENSILE STRENGTH IN POUNDS SQ. INCH
2S0	15,000
2S$\frac{1}{4}$H	14,000
2S$\frac{1}{2}$H	16,000
2SH	22,000
3S0	19,000
3S$\frac{1}{4}$H	17,000
3S$\frac{1}{2}$H	27,000
4S$\frac{1}{4}$H	28,000
4S$\frac{1}{2}$H	32,000
4SH	38,000

6. This is defined as the state of the metal as to its hardness or its elasticity.

From the above table the variation in the hardness of the sheets of the primary common alloys may be determined. The suffix "SH" denotes hard temper and "SO" denotes annealing.

Dural in its many forms offers a wide choice of material strength ranges. Besides the material can be arc, spot, and gas welded; a desirable feature where the material is of the right gauge for such operations. Since welding of thin shell structures is still nearly an impossible problem, the widespread use of riveting has been the accepted mode of joining the various pieces. The limitation of welding is not due to the physical properties as much as it is to the human element on welding thin plates. Assuming distortion to be coped with and the difficulty of following thin lines, welding has not been successful with the limitations in tension of such welds on thin shell plating[7].

Dural machines easily and exhibits good qualities in casting, die casting, and forging. In any of these forms it is extremely durable when heat treated. Where the correct technique has been adhered to in working the material it has not been found wanting.

ALCOA DURAL ALCLAD

In the effort to make dural more resistant to corrosion, a special form of alloy known as Alclad Dural has been extensively employed in structures. This alloy has a coating of 100% chemically pure aluminum on the surface of the sheet impregnated over the dural alloy coring. The thickness of the protective layer and the coring are proportioned for the gauge of the material, so that under the influence of corrosive effects the material stands up well when protected with some sort of surface coating.

The theory of the protection of Alclad is that the outer layer corrodes and, while being attacked, protects the core electrolytically[8] and physically. The stronger the alloy the more susceptible to the attacks of corrosion. With a suitable protective painting, Alclad does not show any signs of physical deterioration and has proved durable in the most exacting service. Corrosion is largely a matter of exposure and frequency of overhaul, and painting obviates troubles from this source.

The newer types of aircraft construction all make a wide use of Alclad on all exterior surfaces. Alclad is well suited to seaplane hull planking, since sea water was a source of corrosion that attacked the pure aluminum sheeting in the earlier prototypes of hulls and pontoons.

The working qualities of Alclad are no different than any of the other sheeting without this outer protecting layer. The material is available in sheet stock in the various tempers and gauges and hardness desired.

Alclad dural is extensively used in the aircraft industry and while not necessarily requiring painting continuously for protection, wherever the gauge of the metal is thin, the surface protection supplementing the Alclad layer is desirable. For heavier gauges this is not necessary. The

7. The shell plating is the thin sheet covering on a wing exterior, fuselage exterior, nacelle exterior, etc.

8. As spoken of here, this means the galvanic action between two dissimilar metals. This usually manifests itself in the deterioration of the weakest metal chemically.

natural finish may be had by buffing and polishing and covering the same with clear lacquer for a lustrous finish.

The strength to weight ratio of any of the dural alloys is about the same with some variation either way, but small enough not to seriously upset the weight calculations. The weight and stiffness is approximately one third that of ordinary mild steel. This means that for the same weight as steel three times as much dural may be used but with an increment in the stiffness - a very desirable feature.

The number of alloys of dural are very numerous and, with the designations attached, may be somewhat confusing. However the table below gives the ones found in common practice.

SYMBOL	DESIGNATION
O	Annealed
H	Hardened
T	Heat Tempered
W	Heat treated at room temperature
RT	Heat treated and cold worked

The correct knowledge of the workability of aluminum or dural alloys is very essential. The right material first of all must be chosen for cold working. If the material fractures under bending, then a different alloy must be used and so on.

Heat treatment is a process whereby the strength of the dural alloys may be suitably increased to various degrees of hardness and workability and strength. Heat treatment is merely heating the material to the temperature necessary and then quenching and aging the same. The temperature of heat is approximately 1000 degrees Fahrenheit and the aging is done at room temperature the length of aging depending upon the material and alloy. The problem of heat treatment is very complex; hence only a light resume can be given here.

Corrosion resistance and heat treatment are very closely related. Unless careful treatment is accorded the alloy, the corrosion resistance will suffer. The quenching[9] and the rate of the same are very important since the aging temperature is also brought into the picture. Artificially aged alloys should not be used at points of great fatigue.

Heat treating furnaces are usually of the warm air type, and the quenching tank close by. The material may be slightly distorted. Restraightening can be done immediately after quenching in the water or oil bath, and then aged. Various items, such as rivets, forgings, beams, bars, etc., all require various methods of heat treatment.

DURAL ALLOYS

The various forms of the dural alloys have found a wide range of application. The varying degrees of hardness and workability may be found in the various parts manufactured of any of the alloys with the required extraneous elements added as desired.

9. The term quenching as used here, denotes cooling of the heated material by the proper cooling agent.

Dural alloys have found use particularly in the field of airplane engines. In the drastic struggle to reduce engine weight, every part possible is made of some form of the dural alloy which has the advantage of being a good casting and capable of being machined easily. The alloy has found use as cylinder jackets of liquid cooled engines, nose sections of engines, crankcases, pistons, connecting rods, and the rear accessory sections. To the success of the radial engine, the use of dural has been a potent factor.

Propellers have always been a source of trouble because of their inherent balance, weight, vibration, and tip speed problems. Yet by the extensive use of dural alloy, propellers have been produced that are extremely efficient and still not over-weight and do have the advantage of being easily serviced and balanced. The blades, if bent, can be straightened. Propeller problems are complex, since a certain degree of flexibility must always be present. At the tips where the stresses are low the tips are extremely flexible.

Wing spars are for the most part in metal aircraft built of riveted dural members. Steel spars have not found a wide application as yet. The dural is formed up in various shapes and riveted together to produce a homogeneous beam structure. The subject of spars is very complex. The dural spar is the strongest for the lightest weight.

Among the first parts of aircraft structures to become metallized was the wing rib. Today this practice is rapidly superseding the wooden rib in all forms of construction. For a high strength to weight ratio dural ribs are ideal. They weigh for moderate chords as little as one half pound yet sustain a distributed load of 500 pounds easily with a minimum of deflection.

Dural in the Alclad form has solved the problem of weight and soakage in seaplane hull and float design. The advantage of light weight and corrosion resistance is two fold. Dural floats are used throughout the world under all sorts of conditions and temperatures without undue damage by sea water. The problems of float and hull building are very simplified by the advent of Alclad.

Tail areas and fuel tanks have been successfully designed with a minimum of weight for their respective duties. Likewise, in the non-structural parts of aircraft, aluminum is extensively used. Tail areas in metal are a simple problem to build and, in most cases, of lighter weight than structures of composite form.

DOW METAL

PHYSICAL CONSTANTS OF DOW METAL ALLOYS

PROPERTY	ALLOY DESIGNATION				
	M	F	E	A	G
Specific Gravity	1.76	1.77	1.79	1.80	1.81
Weight lb.cu.inch	.064	.064	.065	.065	.066
Melting Point	1200	1160	1140	1120	1100
Coefficient of Thermal Expansion	.000016	.000016	.000016	.000016	.000016

MECHANICAL PROPERTIES OF EXTRUDED DOW METAL

PROPERTY	DOW METAL F	DOW METAL E
Tensile Strength	38-42,000 lbs.	40-45,000 lbs.
Yield Strength	27-32,000	28-35,000 lbs.
Elongation in 2"	14-18	11-17
Compression Strength	57-61,000	58-63,000
Shear Strength	19-21,000	19-21,000
Brinnell Hardness	45-50	51-55
Fatigue Endurance Limit	12-16,000	14-17,000

Dow metal forgings have properties similar to above except approximately 12% lower.

Hard rolled Dow metal sheet has a tensile strength of 38-48,000 pounds and a yield strength of 25-35,000 pounds square inch.

Bending radii depends on the thickness and temper of the sheet. A minimum of 3 thicknesses is not harmful.

Dow Metal is actually 25 to 35% lighter than aluminum, when cast.

MAGNESIUM AND MAGNESIUM ALLOYS

Magnesium is approximately one third lighter in weight than aluminum and is derived from the ground from magnesia salt deposits and produced and refined by electro-chemical processes. In the U.S.A. this metal is produced by the American Magnesium Company and the Dow Chemical Company.

The metal, although extremely light in weight, is difficult to work into useful shapes. Magnesium castings by a constant process of refinement and purification are widely used in engine and parts of aircraft that do not have to carry concentrated loads. When combined with certain alloys the material offers a considerable resistance to corrosion, which has been one of its bad disadvantages in its original state. In the light of recent research the use of magnesium is spreading and the material, when properly heat treated and worked, can show a remarkably high mechanical strength.

The commercial forms of magnesium are procurable in forgings, extrudings, rolled shapes, and flat sheet. For certain fabrication requirements a thorough study of the alloy required, however, must be made. In any form the properties of magnesium are less than a corresponding weight in dural on a basis of weight to strength. In working this material the metal must be worked rapidly since the materials harden up more quickly than dural.

Sheet magnesium has found a wide application for non-structural parts in aircraft. The sheets are available in standard sizes and gauges and can be worked with the ordinary tools used in working dural and the riveting procedure is similar.

The following figures show the strength of Dow metal and a comparison can be made with other similar materials:

Highest Tensile Strength		38,000 lbs sq. inch
" " "	Annealed	32,000 lbs " "
" " "	Annealed	30,000 lbs " "

ELECTRON METAL

This metal has been used extensively in Germany. It is widely used for many parts. The development has reached a high state and it is a serious competitor to the ordinary aluminum and dural alloys. The following is a list of the various alloys. The material has good welding properties and should be hot worked. It can be cold riveted. All localized stresses must be eliminated while working.

ALLOYS

AZF: High momentary stresses, landing gears, fairings.
AZG: High fatigue, crankcases
AZM: Extrusion, profiles
AM503: Fuel piping

ROLLED SHEETS

AZM: Structural parts
AM503: Malleable fittings

Electron metal is widely used in parts subject to high stresses when properly heat treated. The metal for the most part is heavily alloyed with magnesium, and is about one-third lighter than ordinary dural.

FORGINGS

A forging is nothing more than a casting produced and worked while in the molten state and then properly cooled. Forgings have the advantage of cheap production the same as castings and also possess ample, sufficient strength for the design purpose. They are produced economically in large quantities in the various alloys. The forgings are produced under the action of a power hammer that shapes, by pressure and a series of blows, the metal into the form required by the matrix die. Forgings have found wide application in motor parts.

BENDING AND FORMING

Because of the special technique here required, this apparently simple operation is complex. Bending, without fracture or setting up of intense localization stresses in dural sheeting, is based on a number of factors. The minimum permissible bending radius depends on the type of tools, equipment and the design of the part. The minimum radius can only be determined by experience.

In bending, naturally, the radius of the bend is dependent on the equipment and the gauge of the material. In any case the radius should be made as large as practical to avoid severe strain on the metal. As a general rule the soft alloys like 2S0, 3S0, can be bent on short radius not less than one gauge thickness; while the harder alloys, like 24SRT, must not be bent on radius less than 4 to 6 gauge thicknesses, depending, as well, on the gauge of the material. The heavier the gauge the greater

the radius, and vice versa. The correct amount to bend the various alloys can only be determined by experience.

In bending, all burrs and sharp corners should be removed from the tools which must be well lubricated. The bend should be at an axis or right angle to the rolling grain of the material. In thin sheet shell plating and forming of light gauge structures the outer surface should not be allowed to be scored, no matter how minutely, since the working strength is seriously undermined. This seems like an extreme accuracy that is unnecessary, yet any scoring immediately lowers the strength of the thin sheet gauges enormously, and this thought cannot be impressed too strongly.The material should not in any case be burred or scratched, and the use of paper on the tools to protect the outer finish is advised on the basis of strength.

CASTING ALLOYS

For certain parts in the fabrication of aircraft, a casting is better and more economical to manufacture than a corresponding structure built up of component parts and riveted together. Prior to the advent of light durable heat treated alloys, casting was unheard of in relation to the structure of an airplane on the basis of great weight to strength. Thanks to the heat treating, this disadvantage is obviated.

For instance, there are many parts of a plane where castings can be economically employed, such as in the control system, the empennage, engine mounting, landing gear parts, and the like. Casting has the advantage of being uniform after the right amount is estimated for shrinkage, and the fact that they can be machined to size and made uniform. Casting has been widely employed by the Douglas Company for many parts.

Castings are always alloyed with some sort of hardener, and either produced under pressure, permanent metal molds, or sand molds, depending on the requirements of the job. The best castings are made in the metal mold. The type of casting process is limited by the quantity.

After the castings have cooled from the molds they are subsequently heat treated in the usual hot air furnace used for sheet and bar stock, and aged. The addition of magnesium causes the aluminum to have a high degree of strength, although a certain amount of flaws and blow holes sometimes result from this form of casting unless it is manufactured correctly. Magnesium alloy castings are used extensively in motor design, and have proven to be well adapted to the job.

EXTRUDED SECTIONS

Dural alloys are workable enough in their parent state to be rolled or drawn or extruded to standard shapes. These standard shapes comprise a complete line of angles, bars, rods, tubes, streamline strut sections, and other shapes required by the aircraft industry.

The material is taken from the furnaces and formed while hot under the action of powerful forming dies. The structural shapes are produced in the same way, and then aged. After aging and cooling at room temperature they can be heat treated again, and aged when under the course of fabrication. The dural alloys are available in practically every structural form required.

LAUTAL

This metal is produced by the Lauta Co. in Germany. It is a material of the aluminum family alloyed with certain other elements, enough of which go to make it of the same strength or equal to the ordinary dural material so widely used.

Lautal is a refinable aluminum alloy but, unlike the other dural alloys, contains no magnesium. The refining process is the same, chemically, as that employed to manufacture the dural alloys. The material is heat treated to 937 Fahrenheit, and then quenched in water and artificially aged for 24 hours at 250 degrees Fahrenheit. The material is refined from Bauxite, the same as dural.

The Lautal alloys are available in sheet stock of various hardnesses, extrusions, forgings, tubings, and other preformed parts. The material can be welded although the tensile strength is reduced at least 25%. The shearing strength is nearly 38,000 pounds to the square inch. Rivets of this material are of the soft alloy, and the riveted Lautal joints compare favorably with dural or Electron. The fusion type of welding is the method mostly employed although the other forms of welding are undergoing experimentation at present. The same form of flux is used in fusion welding which dissolves the oxide of the material as it forms from the process of welding. Lautal welds can be strengthened by heat treatment.

Lautal is a serious competitor to heavier alloy construction materials, and has acquired foreign letters of patent so that its use will be universally available shortly.

HIDUMINIUM

This is a magnesium alloy extensively used in England in motor castings. The Rolls-Royce engines contain numerous parts of this alloy, the same alloy being used in the water jacket. The material is patented, and weighs about the same as Electron metal. Hiduminium has the special property of heat conductivity. It has been used in modified forms for the various types of casting ordinarily required in fuselage and wing construction as well as non-structural parts for the landing gears.

STRIP STEEL

This type of structure has found wide favor in England in comparison to the all metal shell type construction. The material is of the high tensile variety, and rolled into a myriad of structural shapes by means of roller dies.

The various members are built up in a jig construction and riveted together into a solid frame structure, and wire braced for additional strength. This form of construction is extremely light for its strength and is not subject to corrosion, since rustless stainless steel is utilized in long strips and passed through the sequence of roller dies to the finished section.

Strip steel is ideally suited for wing structures. The wings are covered with fabric and are extremely light and strong for the weight

per square foot. All members are riveted together. Strip steel construction offers the maximum of accessibility for inspection by quick removal of the fabric cover. Aircraft built of this construction have been used in wide numbers by the R.A.F. in service. Ordinary repairs are accomplished in the field with a minimum of tools and parts since the shapes are carried as spares.

Strip steel has not found wide favor in the U.S.A. as a material for the frame structures, mainly, because of lack of knowledge to roll the sections through the dies, and the scarcity of the raw material. Aircraft built of this structure are somewhat more costly than the welded fuselage wooden wing type so popular here from the angle of cost. Production of strip steel undoubtedly means a high production cost. On the other hand, the plane is durable and can be built stronger for equal weight than other alloys.

In the field of rib construction a fabricated strip steel rib in composite construction should offer wide possibilities for aircraft use in the U.S.A. Wings, however, built with this rib construction must be braced strongly against torsion, since the wings using this type of steel have great resiliency.

CHAPTER III

AIRCRAFT CONSTRUCTION TOOLS & TOOLING

GENERAL SUMMATION

The fundamental essentials of the working technique of metal fabrication for monocoque and stressed skin aircraft structures involves many operations of an accurate nature in the sequence of production. This form of metal work, while a branch of the art of "sheet metal", is varied by many requirements of manufacture from the usual practice in the commercial forms of sheet metal work in the ordinary sense of the word. Accuracies and methods approaching a very high degree of technical skill are required.

The foremost requirement for working in this line of aircraft work is the need of being accurate in every detail, large or small, and perfect workmanship in everything. This branch of aircraft work involves the use of extremely light gauge metal alloys of delicate nature, subject to deformations by the slightest strains, and rendered useless unless the correct method is followed in the fabrication throughout the entire process.

The words "shell structures" are indeed fitting and descriptive of monocoque all-metal structures. The modern transport plane is essentially a thin shell plating with a skin infinitely thin, about the thickness of two sheets of heavy paper, in relation to the linear dimensions and the loads carried. The thin shell structure must resist at all times, heavy stresses and accelerations, plus vibration. The stresses on a modern plane, at times, rise to enormous momentary values. The need for good workmanship and high strength is obviously imperative. Poor workmanship may entail a structural failure with consequential serious results. Latest designs of monocoque and stressed skin transport planes carry as high as 95% in useful load of the gross weight empty. They do this at velocities exceeding 200 miles per hour. To the tyro airplane fabricator the habit of accuracy must be first inculcated into every operation pertaining to metal airplane building.

The importance of accuracy is paramount, not primarily so much from the technical aspect as the fact that the delicate materials employed in these structures can be rendered unfit structurally by coarse or sloppy fabrication. Fabrication procedure of this sort would hasten the time that fatigue would be liable to occur during the life of the plane. Defects such as these do not show up until later in the life of the plane. Such defects may cause sudden structural failure at some inopportune time. No detail is too small to ever warrant lack of good workmanship in metal airplane fabrication.

LIMITATIONS OF LIGHT STRUCTURES

In the fabrication of light shell structures of the monocoque or the stressed skin type, highly concentrated or localized loads of any

sort weaken the structure. The efficiency of a structure of this kind to resist loads depends on spreading the loads over a large area, and so reduce the unit loading per square inch.

In shell structures it is best to remember that every outer skin plate member is in tension while subjected to flight loads. Failure results in crinkling of the skin and then shearing of the metal around the rivet holes. The metal, when loaded beyond its extreme structural limit, first shows evidence of crinkling, with the rivets themselves acting as the restraining elements. If the force is then increased the rivets shear through the outer shell rivet holes and cause failure.

In handling metals of the dural alloy group, care must be exercised to prevent preliminary bending, scoring, kinking, or twisting. The material should be stretcher leveled[10] flat stock before fabrication begins. A monocoque structure, at best, is very delicate.

In riveting any work about the structure, care must be exercised in the handling of the heavy rivet tools. Denting requires bumping and pounding to straighten, and this alters the metallic strength. The delicate monocoque structure if damaged may induce failure in other structural parts dependent on it for strength and support. Any mishandling of the metal or tool handling is contributory to failure of the light structure.

The light structure must be stiffened with structural elements so disposed that they can absorb the heavier skin loads and distribute the same over a large area. Stiffeners for light weights are generally a hollow channel or circular section for lightness and riveted to the shell. The shell itself is weaker than the rivets holding the same together. Under strain the shell plating fails first.

A flat sheet is an elemental form of the simple beam. When under tension, as in a monocoque fuselage structure, a radius subjects the sheet to a bending stress. The ability to resist bending is multiplied if the force is in opposition to the direction of the bending force. Stiffeners in this respect absorb, resist and reinforce the thin shell plating, and act in the capacity of restraining agents to the forces of bending. The strength of the stiffener depends on its shape and the spacing of the same on the shell structure. The greater the diameter of the radius of the bend of the shell plating, the smaller the induced internal forces in the skin itself. On large fuselages or wing curves, the metal may be sprung into place without preliminary preforming. This is, of course, within the limits of the material itself.

Flight loads induce forces in the fuselage with the top skin plating of the fuselage under tension. The bottom skin plating is in compression. Likewise landing loads act in the same manner. Under the con-

10. Sheet stock material of the light gauges can be purchased from the rolling mill two ways. Where the material is used non-structurally ordinary mill sheets may be used. Where the material is used to carry high stresses, such as in wing and fuselage covering, stretcher leveled sheets are used. Stretcher leveled means sheets that are absolutely flat and rigid. Such sheets are packed in flat crates. The other sheets are packed in bundles clamped together. Stretcher leveling is done on a special machine that grips the sheet at the extremities and by a mechanical arrangement stretches and levels the sheets for use. For stretcher leveled sheets the gauges are very closely controlled to exact limits. This material costs more to purchase. The other material is sometimes referred to as ordinary mill sheeting. Stretcher level sheets are sheared square and accurate while ordinary sheets may vary somewhat in this respect.

ditions of high accelerations both in landing and flight conditions, these longitudinal bending loads rise to high momentary values per unit area of the fuselage structure.

In actual design there are two ways to get around these loading conditions and yet not add an increment of useless weight. One method would be to make the moment of inertia of the fuselage greater by increasing the depth. The other can be done by stiffening the top and bottom shell plating with heavy stringers or external corrugating plating over the smooth shell.

ESSENTIAL FUNDAMENTALS FOR THE USE OF MATERIAL.

The family of alloys, commonly known as "dural", is very numerous. To derive the maximum of efficiency and strength, the use of the alloy best suited for each requirement must not be deviated from. For example, pure aluminum, being soft, is used exclusively for non-structural fairings. Fairings always require forming, and naturally a soft material must be used for this.

The use of dural alloys that cannot stand much working are used for bulkheads and other structural parts that do not require much forming or deformation. The "SRT" alloys are the strongest of the whole group. Any alloy of this kind is worked as little as possible with a minimum of forming. This alloy would be used for flat or slightly curved surfaces, such as the wing or the fuselage side skin.

Aluminum, which is soft, is worked in the same manner as copper is worked by a coppersmith. Aluminum would be used for non-structural fairings and parts requiring compound curves, spheres, spinnings, etc. The various aluminum alloys are graded to their various hardnesses as 1/4 hard, 1/2 hard, etc. Aluminum can be welded.

Next in use is the alloy group known as 17S0, the S-0 denoting soft or annealed. This alloy is used for parts that do not require welding but do require a hard finish. The alloy 17S0 cannot be welded successfully. It has a lustrous hard finish and can be heat treated and hardened to a greater density than the material known as "SRT". It cannot be worked or formed after it has been through the heat treating process.

Next in order comes 24S0 alloy. This is slightly harder than 17S0 and has somewhat greater strength. This is used in a similar manner to 17S0. It can be machined or punch pressed in a rubber die press with good results. Both 17S0 and 24S0 can be worked up to a very hard state, but care must be exercised as these alloys are both more brittle than aluminum.

The hard dural alloys are 17ST, 24ST, 17SRT, 24SRT, 17STAL, and 24-STAL. The last two are used for exposed surfaces subject to corrosive deterioration, and have a pure aluminum coating. The choice of dural sheeting or structural shape is, therefore, a function of what the material will stand and what it is best adapted to.

In fabrication in good shop practice, the metal worker receives a detail of the piece with all the information required. Included in this is the minimum radius the material will stand, and also the radius that will be exactly right for that particular alloy specified for the part use. This is done to prevent inferior workmanship. If the radius was too

sharp, the metal would crack or fail on the brake or the mold line. A reference to a chart of this form would show how much is gained or lost in an operation of this kind.

In working the dural alloys the hardness or degree of the same will determine the bending radii. For example: 17SO will stand a smaller radius than 17ST, and so on all the way up and down the range of the dural alloys. These fundamentals can be applied to any of the other operations in the working of dural alloys. These fundamental facts should be thoroughly understood before attempting any form of dural fabrication. As a general axiom, the harder the material the less working it will stand without strength impairment.

SHEARING

Shearing is the first essential operation in production. The shearing operations determine the sizes which, in turn, are required for the various parts of the structure. Shearing is a cutting operation performed on flat sheets with knife-like tools.

The shear machine in its various ramifications must be thoroughly understood. Sheets are shipped from the factory in the flat form in wooden crates in sizes and gauges common to the needs of airplane work. The sheets are then assorted as to gauges and sizes. A shearing list is made up from the various engineering details as well as a cutting schedule. Shears are power driven for heavy gauge work and foot driven for light gauge small dimension work. Small tools of this type are the squaring shear or the foot shear. The shear is essentially a steel knife set diagonally. This knife moves in the vertical up and down direction. It is actuated by a suitable power drive and controlled by a foot pedal.

The shear machine is built in various capacities and lengths. Each type and length is utilized according to the size of the sheet to be operated on. The shear machine is used for squaring and trimming irregular edges. The table of the machine is plumbed and level, of cast machined steel. The table is equipped with adjustable slides or stops or gauge screws for establishing the cutting sizes of the sheet stock ready for shearing. The adjustable stops are moved backwards and forwards as desired. They are tightened in place when a large number of pieces of a certain specific size are to be sheared. Uniformity is assured in production work.

For fast production the shears may be automatically operated or manually controlled. Power shears will cut up to 1/4 inch sheet stock easily. Production shearing requires a different initial set up in order to produce the best results. This type of shearing is limited to certain sizes of sheet stock.

For smaller cutting sizes and lighter gauges, the smaller foot or squaring shear is used. These machines cut up to 18 gauge sheet stock. The essential principals are the same as the larger types. The smaller machines are used for cutting interior non-structural pieces, web plates, gussets, and small production piece work. They may also be employed in motor driven form.

To facilitate rapid production and to reduce cost, certain factories employ cutting dies on the shears. These dies cut the clearance holes

for stringers and longerons. This lowers the cost and makes for uniformity. Uniformity is one of the best advantages of metal construction.

For very light gauges and small parts where accuracy is secondary, hand shears manually or electrically driven are employed. Tools of this sort are merely an accessory hand tool. Angle cutters and bar cutters are utilized for rough cuts. It must be remembered that any shearing action must be free from burrs or coarse cutting edges, and the tools must be sharp.

Where squareness, accuracy, and uniformity are required for heavy structural parts after forming, the power driven metal hack saw is used. This saw is suitable up to 1/4" thickness. The power driven metal hack saw can be set to an accurate dimension and the cutting speed can be regulated for the various physical characteristics of each alloy. A vertical stopping face plate to limit the cuts enables uniformity. The cutting speed for each alloy is different and depends on the hardness of the metal.

For short tubular members, either rod, tube, or bar, the use of the lathe with a cutting tool can be advantageously employed for close accuracy.

PUNCHING

Any form of punching in structural parts is not advocated in duralumin alloys if it can be avoided. All holes should be drilled. In punching, the operation is essentially a tearing action. After a hole is punched the strength of the metal is altered - detrimentally altered. The result is that the metal strength will have been lowered in bearing strength. The correct procedure is to punch small holes and then ream the same to size. Punch pressing offers a means for cheap production. Drilling is the best practice.

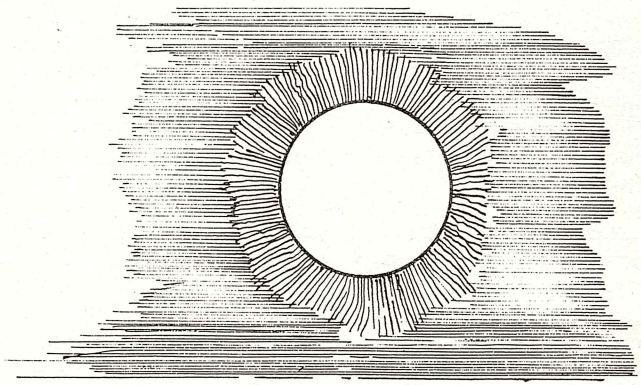


Figure 1

SHOWING LINES OF FORCE AROUND A RIVET HOLE FROM PUNCHING. NOTE THE DEVIATION FROM THE GRAIN OF THE METAL, AND THE AREA OF DEFORMATION.

In non-structural elements, punching can be utilized for lightening holes. The edges of the holes should be free from burrs. This is only possible when the correct clearance is allowed and a sharp die used. For small holes, if they must be punched, a spiral fluted reamer is best adapted to hole reaming. The low strength of dural alloys, in comparison to steel, allows the use of small punch presses. The punch press is always motor driven. It consists of a table plumbed and leveled, with the two dies aligned over each other on the same. The male die is usually attached to the vertically moving arm and the female die is anchored on the table. The arm moves up and down and under the control of a foot pedal. Punching of angle cut-outs or grooving are accomplished with machines of this sort. Punching is suitably adapted to lower the cost in production operations where it can be used without lowering the strength of the material.

BRAKE WORK

In the manufacturing of metal aircraft the brake tool in its various styles is a most essential tool. Braking is forming flat sheets into various shapes. "Brake work" is the expression for this phase of forming. Braking sheet means bending the sheet either to an angle shape or mild radius shape. Two types are used in brake work.

The brake is used in the hand form (leaf brake) and the power brake (leaf form). The other type is hydraulicly operated. The hydraulic brake is mainly a forming die that operates up and down vertically. One element of the drop brake (moving) has the male forming die and the other has the female die. The hydraulic brake, for example, is utilized by the North - rop Company in forming up stringer sections, shell plating, etc., peculiar to their type of construction. The hydraulic brake is the most economical to operate. It is very powerful and positive in its action. Enormous steady pressures on formed sheets are possible without vibration or inducing severe local stresses in the sheet stock.

Dural alloys are very low in strength when compared to ordinary sheet steel stock. The straining of the metal crosswise (remember the metal has grain) and the slip layers, or vice versa, lowers the modulus of elasticity. When this occurs the formed part is understrength. Any forming operation or bending requires that the sheet stock be lubricated with suitable lubricants for this purpose. This reduces the strain. If the surface is polished care must be exercised to avoid scratching.

Under no circumstances should a sheet of material be broken around a sharper radius than the material will safely stand as specified for that particular alloy of dural. There is a minimum radius for every gauge and number of alloy.

In any braking operation, one half of the metal sheet in thickness must stretch. The other half must compress. If this forming operation is severe in method, the molecular structure is altered with a subsequent loss in design strength.

The drop brake is available for accurate forming of long special section lengths. The forming dies are adjusted for clearance and metal stretch for the gauge and form. The machine is operated by a foot treadle and requires, in the larger sizes, two men to operate the same. String-

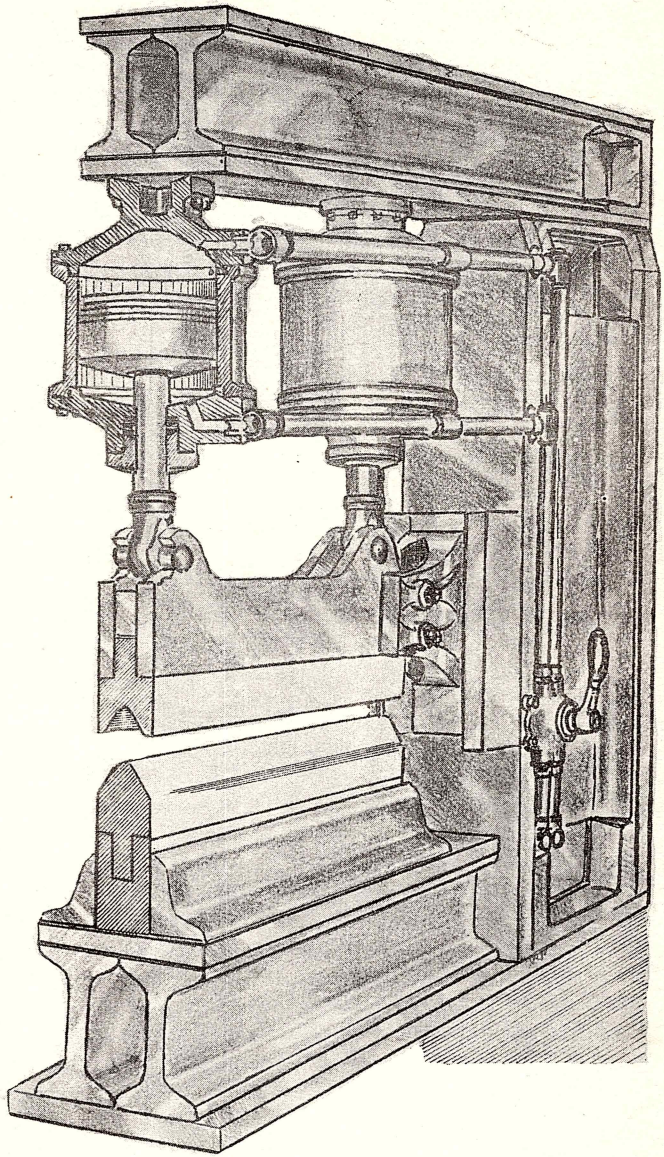


Figure 2

THE HYDRAULIC SHEET METAL BRAKE

ers, longerons, and spar elements are all produced on drop brakes. Spar sections are difficult to built accurately, and here the efficacy of the drop brake is best exemplified.

For small pieces and sheet stock of light gauge, braking can be done on a modified punch press or nibbling brake. Non-structural parts and trim pieces are produced in this method. For uniformity, unless stops are provided on the hand brake, it is almost an impossibility to repeatedly brake to the desired angle. The natural tendency is to make the brake too great or too small, or strain the metal around too severe a radius.

For non-structural parts, hand braking suffices in most cases when done by an experienced sheet metal worker. Small brakes of this type are available in ten foot lengths although beyond four feet in length, it is best to use a power brake or a drop brake. Drop brakes are a machine for production work only. The dies for forming and the time to align and install the same makes this machine unsuited for many different brake formings. Therefore, for various small odd braking jobs the small hand leaf brake is more readily adaptable. The hydraulic brake is merely an adaptation of the orthodox drop brake. The sole difference is in the method of applying the power.

DRILLING

The drilling of rivet holes is a very serious operation. It involves accurate spacing, speed of the drills, type of drill, feeding speeds, and lubrication of the drills. Rivet holes are always drilled a fraction less and then reamed to size. This is good practice to apply to any form of pin joint.

In production work, the press drill and stand can be used for straight structural members. The members are located on the drill table and the drilling operation performed. The members are then slid along to a stop and the next drilling takes place. The stop acts as a spacer in locating the holes. Where there is a close spacing of the holes, such as in riveting, the holes are all marked and center punched. The pitch of the holes is identical. Hole spacing is done by means of long metal templates accurately made beforehand for this purpose.

There are three special kinds of drills used for the drilling of dural alloys. They are the single flute twist drill, the double flute twist drill, and a special double fluted twist drill. The angle of the cutting point is adjusted for the best speeds and the feeding requirements of the alloy to be drilled. A cutting compound or lubricant should be generously used on the point of the drill while drilling. The drill should be cleared frequently and not allowed to heat. All drills must be sharply pointed for good hole edges and fed into the material at moderate speeds.

In the effort to cut production costs multiple drills have been resorted to with automatic spacing and pitch of the holes accomplished at the same time. Multiple drill presses of this sort are capable of drilling through several layers of sheet stock when clamped together. This is a rapid method to lower the cost of preparing the shell plating of the fuselage prior to riveting. In most cases the outside shell plating rivet pitches are identical.

.125 = 1/8
.0625 = 1/16
.0312 = 1/32

DRILL SIZE DATA

TWIST DRILL NUMBERED SIZES

NO.	SIZE IN INCHES
1	.2280
2	.2210
3	.2130
4	.2090
5	.2055
6	.2040
7	.2010
8	.1990
9	.1960
10	.1935
11	.1910
12	.1890
13	.1850
14	.1820
15	.1800
16	.1770
17	.1730
18	.1695
19	.1660
20	.1610
21	.1590
22	.1570
23	.1540
24	.1520
25	.1495
26	.1470
27	.1440
28	.1405
29	.1360
30	.1285
31	.1200
32	.1160
33	.1130
34	.1110
35	.1100
36	.1065
37	.1040
38	.1015
39	.0995
40	.0980
41	.0960
42	.0935
43	.0890
44	.0860
45	.0820

This table of the numbered twist drill sizes can be used in conjunction with the other tables such as decimal equivalents, the equivalents in inches of the gauges, and the rivet sizes. In this way the correct size of the twist drill can be determined for a given hole diameter with a minimum of reaming.

.312 = 5/16
.936 Quit Drg
1248

.936 = 3/32 Rivet

DRILL SHANK DATA

DECIMAL EQUIVALENT OF LETTER SIZE DRILLS

LETTER	SIZE IN INCHES
A	.234
B	.238
C	.242
D	.246
E	.250
F	.257
G	.261
H	.266
I	.272
J	.277
K	.281
L	.290
M	.295
N	.302
O	.316
P	.323
Q	.332
R	.339
S	.348
T	.358
U	.368
V	.377
W	.386
X	.397
Y	.404
Z	.413

In studying the action of the twist drill in the light gauge alloy, the tendency of the flat sheet is to twist or crinkle. To avoid this the flat sheet stock must be firmly clamped down to the drill table. Failure to do this may damage the sheet beyond retrieve. Lightening holes in light gauge material are oftimes cut with a radius cutter or extension bit. The center is punch marked and the radius cutter fed in very gently, taking small cuts at first. If done in this manner no severe twisting of the sheet will be possible, and the circular cut-out will be free from burrs around the edge. Circular cut-outs are subject to the same edge stresses as punched rivet holes unless precautions are observed in this procedure.

Drills are available in the numbered and the lettered sizes. The numbered sizes are the small class and the lettered sizes are the larger diameters. Drills should be sharpened frequently. The soft material will wear a drill cutting edge by virtue of the low feeding speeds used in the operation of drilling of dural alloys.

Press drills are utilized for many purposes in connection with aircraft construction. The press drill can be used for lapping in machine parts. It may also be used for grooving with a suitable tool around the lightening holes for strength. This latter operation is performed by a radial grooving tool and fed slowly. Allowance must be made for stretching of the metal. This operation requires a female die for the metal to be forced down into place with an allowance being made for stretching. This is best done by punch press or forming presses;otherwise it deforms the edges.

In random hole drilling, where the hole centers are not spaced by template,the center should be center punched first as a guide. The drill must be absolutely vertical to the stock to be drilled. The drill press should be free of vibration. In random drilling, starting the drill by means of a center punch mark is good practice if the shank of the drill is slightly eccentric. With a punch mark any small eccentricity may be corrected.

PRESSED PARTS

The fact that dural alloys are soft adapts them instantly to the process of pressing with dies for ribs and other parts making up the structure. Pressing is essentially a production operation. Its cost depends on the amount of the work to be executed. For a single plane its cost would be prohibitive. For a production order it would be warranted, not only for cost but for uniformity and interchangeability. The use of the press has made the interchangeability of aircraft parts a reality. This reduces maintenance fixed charges.

Pressing or forming of shell plating is accomplished on the ordinary hydraulic press. For ribs or lighter structural parts it may embrace the use of blanking dies. For example, the fuselages of the Boeing P-26A Fighter and the Boeing 247-D aircraft employ hydraulically pressed outer skin plates on the fuselage. Nevertheless, while expensive, it is the best method. A pressed shell plating may be applied more quickly than one that needs to be sprung into place. The saving and the uniformity possible are obvious.

Parts most frequently pressed in punch presses are wing parts and rib parts for the lighter gauges. The airfoil profiles are cut with blanking dies. The dies are either of wood or steel. Hardwood, while economical, needs frequent renewal. Of late, rubber dies are being used on light gauges successfully. Successful ribs have been built by pressing the same, flanging for strength, and making a rib amply strong in twisting conditions. These pressing operations must be accomplished without stretching the metal. The amount of clearance can only be determined by experience. Die forming is essentially a tearing action. As an axiom to be remembered--the harder alloys are not suitable for die press work. The harder the metal the more difficult to form. The softer the metal the greater the stretch without fracture.

SPINNING

Spinning is a coppersmith's operation. The soft aluminum 2S0 & 3S0 spins nicely into shape on an ordinary spinner's lathe. The metal in the

thin gauges works up easily cold into many various shapes. Spinning is a production operation to lower cost. It might be intimated that any part that can be spun or that is round, such as nose spinner, tail cap, etc., can be produced cheaply in any quantity. The lathe in any form is a very economical tool to operate.

Dural is best spun when heated and annealed. For non-structural parts, the softer alloys are best utilized. They possess greater ductility and assume the desired shape easily. If strength in the particular part to be spun is required, the material is annealed first to the necessary softness; then spun into shape, allowed to cool, and afterwards heat treated and aged.

Patterns for spinning work are cut from flat sheet stock. The center of the pattern is attached to the chuck of the lathe. The tail stock of the lathe is used to carry the wooden form or mold that the material must be spun over. Pressure is applied to the spinning tool on the tool post of the lathe. Pressure is applied on the latter with the flat pattern revolving. The spinning tool is round nosed. The feed of the tool forming the spinning may be automatic at slow speeds by use of the lathe lead screw automatic feed or else done by hand. In any case the result will be the same, depending on the skill and experience of the worker. Here, as in any other case, the speed and pressure is governed by the gauge, the material, and the spinning radius for that particular alloy.

ROLLS

In the production of curved parts, so many of which make up the shell plating of the monocoque fuselage, the roll is an indispensable machine. This operation accomplishes cylindrical forming.

The roll is simply a machine, motor driven, that comprises three long rollers of steel. The diameter and the arrangement of the rolls as well as the length is governed by the production requirements. Sheets of flat stock are fed into the machine. The rolls are set to give the required curvature.

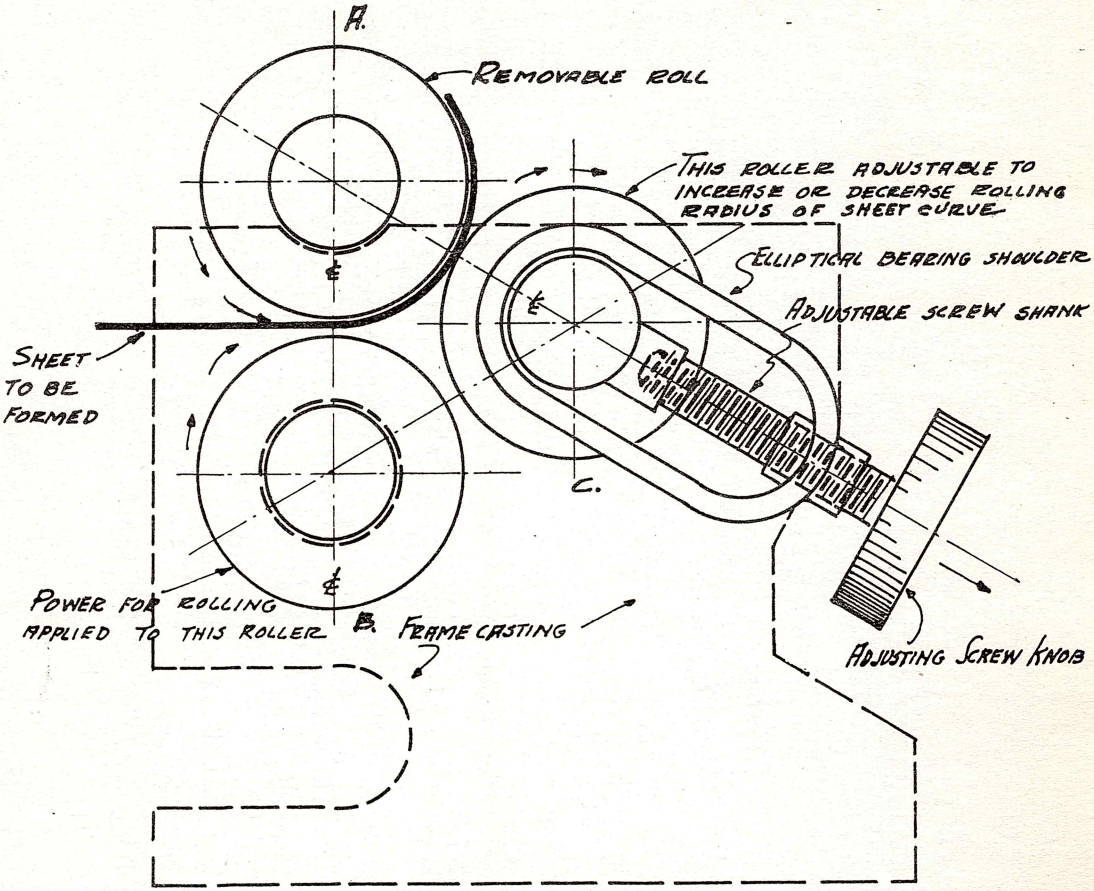
In rolling a sheet, as in any other operation, severe deformation must be prevented. The outer surface is stretched and the inner surface is compressed. The roller produces a stretch in the sheet. The amount is determined by experience for each gauge and each alloy.

Small bench rollers are used for small part work. They are not uniform, however, in their forming, sometimes requiring the sheet to be run through several times before the desired radius is formed with the sheet.

CORRUGATING

The use of corrugated sheeting is found extensively in metal structures. Junkers Aircraft used this at first during the World War. Corrugated wing covering possesses great strength to all normal wing loads. It, however, increases the drag 1%, and gives 10% greater lift for a given area. The effective area is increased by the corrugations.

The corrugated sheet stock is procured direct from the factory. The sheets are produced by the process of roller dies. Corrugated sheets have increased strength to bending in any direction. They are a modified version of the simple beam. The neutral axis of the sheet is through the



PRINCIPAL OF ROLLING SHEETS

ROLLERS "A & B" ARE CONNECTED TO EACH OTHER BY SPUR GEARS AT THE OTHER END OF ROLL FRAME. IN ACTUAL ROLLING, CLEARANCE BETWEEN C & A ROLLS DETERMINED BY GAUGE. WHETHER POWER OR HAND DRIVEN PRINCIPAL IS SIMILAR. ROLLER "B" IS ADJUSTABLE FOR GAUGE SIZE.

Figure 3

center with the material equally disposed about it. The strength of the sheet depends on the radius of the corrugations for a given gauge, and the greater the radius of the corrugations the greater the resistance to local failure by virtue of the increased moment of inertia of the sheet.

Corrugations for special work may be done, if for non-structural purposes, in the ordinary hand brake. However, this takes much time. The material is used chiefly for floors, bulkheads, and inner wing skins disposed laterally to aid the wing stiffness. It is being discarded for wing covering in the latest designs due to high skin friction losses.

SKINNING

Skinning is the name given to the operation of applying metal to the wing covering, or the metal fuselage shell plating. There are many ways of laying on the covering. On large wing structures, the vertical skinning jig is the best. When the wing structure is complete it is jacked up on a jig with rollers on the same for mobility. It is then wheeled to the skinning department.

On small wings, where the nose curves are of sharp radius or sharp bends and reflexed curves, the sheet covering of the wing or the fuselage should be preformed. It would then be bolted into place temporarily and riveting operations begun. The outer cover would be first tack riveted, and then riveted up complete.

On large wing sizes with large curves and profiles of big radius, the outer skin is laid on to the wing structure or fuselage structure as the case may be, by springing the metal on to the structure. The outer cover would be held by temporary straps. Then the sheets would be tack-riveted to the structure of the wing or fuselage, and so on until completed.

Preforming has always a slight tendency to stretch the metal while forming from the flat stock. Springing the outer shell plates in place cold is a better method. The larger the plane structure, the larger the size sheet that can be laid on. The greater the area of the shell plating sheets, the greater the degree of strength. Wing skins, being more or less uniform for profile and curve, are always laid on in sheets as large as possible. The fuselage skin sizes vary for laying on operations. The curves fore and aft and the top and bottom of the same require various sheet sizes and some preforming.

In the skinning operation for the wing, the nose section is always laid on first unless by virtue of large dimensions, the nose radius allows springing the skin into place. Preformed nose sheets are riveted first, and then the skin is applied toward the tip and to the trailing edge simultaneously.

Seaplane hull structures are built upside down. This method is the easiest and most convenient way to apply the hull shell plating and riveting the same to the former bulkheads. If the surfaces to be covered are flat or slightly curved, the sheets are sprung on. They are preformed for sharp radii and sharp bends.

Seaplane floats are built out of preformed material. The skinning operation is the same as in other skin covering procedure. The shell plating for floats is mostly in small sheets, closely riveted to the bulkhead formers.

JIGS

In skinning the wing, the structure is placed in a jig form built up specially for the purpose of angle framing. The jig is cushioned with rubber to prevent damage or chafing of the structure while skinning is going on. The jig is built of heavy angles and channels welded, or bolted together if detachability is necessary. The jig is so built that the wing is on a slant in the vertical position. This enables the skinners at work to lay on the metal, and work from two sides with single shot riveters. This is done to enable the heading up of rivets to be better accomplished.

The fuselage is generally built in a rectangular form of jig built of heavy angle and channel held by clamps and bolts. The fuselage in this way is always lined up symmetrically while being assembled, and accuracy and uniformity are assured.

In covering a large dimension fuselage with numerous closely pitched rivet holes in each shell plate, the temperature must be allowed for. On long runs the expansion coefficient of the material is such that it can throw the rivet holes out of alignment. Skinning operations, therefore, on long runs must be done at a constant temperature. The jigs must prevent distortion.

To prevent waves in the sides of the fuselage shell plating much depends on the use of level sheets. When racked away before use, the sheets should be stacked edgewise. They should be protected in order that no permanent set can take place in them. This is a necessary requirement for good workmanship. A straightened sheet is worthless for good skinning operations. As it is, enough waviness is noticeable in production fuselage work regardless of effort to prevent it.

Spar jigs are another way to produce uniform parts in production. The spar jig is always on a long flat table with special hold down members by which the spar is clamped and held down. All holes are drilled while the spar is in the jig, both for riveting and fitting. In this way each spar is uniform and the work more quickly effected, as well as a method to find rejected pieces more easily.

Building a metal spar without jigs is nearly an impossible job. For cheap production work the jig should make construction of any part merely a sequence of semi or unskilled metal working operations and assembly. Jigs eliminate the chance for error and make the ruler unnecessary for the workmen to use. The parts are held firmly, preventing movement. Drilling and riveting are done in the usual way. Squeeze riveters are used. The holes are drilled with electric drills, either portable or on a special production jig frame arrangement overhead above the spar. The simplest jig is the most efficient. The table where the jig is mounted should be level and true.

In spar construction the jig design varies as to the type and the design of the spar. A simple jig is shown in Figure 4. The spar is a simple "I" beam section with reinforcing angles under each flange, and the flanges and the stiffening angles all riveted together.

The clamp is of cast iron. The angle stop in front runs the length of the table. The clamp can be opened at the back. The clamp fittings line up the spar in the rear. In this spar the web is a sheet of dural.

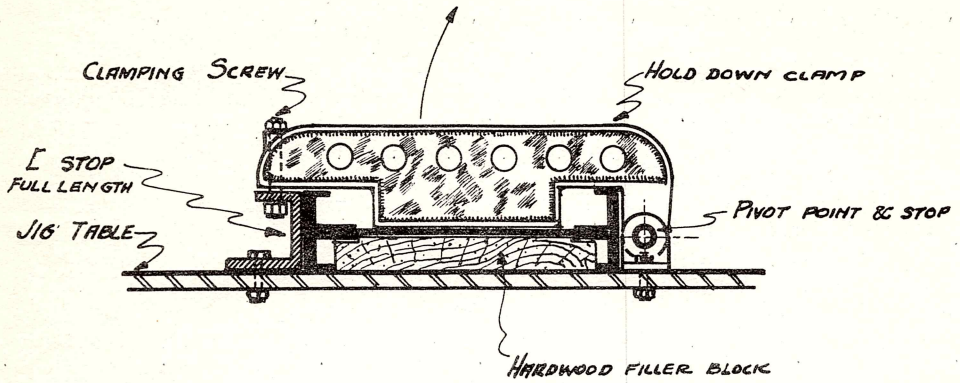


Figure 4

DETAIL OF SPAR JIG

The web is supported in the jig by a hardwood filler piece running the length of the jig table.

In assembly, the two outer flanges are lined up plumb and true. Then the web is riveted to the angle stiffeners. The stiffeners, in turn, are riveted to the spar flanges. The clamps are placed every two feet along the spar length. All the holes for riveting and fitting are drilled with portable drills while the spar is jigged up. The hardwood filler piece is cut to clear the angle stiffeners. For working on either side, the spar is removed and turned over for riveting operations first on one flange and then the other. In this way uniform spars can be produced with rapidity and semi-skilled labor. They will be straight when removed.

The rib jig shown in Figure 5 is an example of a special riveted strip section rib. The rib parts are rolled on the sharp curves and sprung on the long radius. The shear members are then placed in the grooves for each, which are located by the position of the filler block

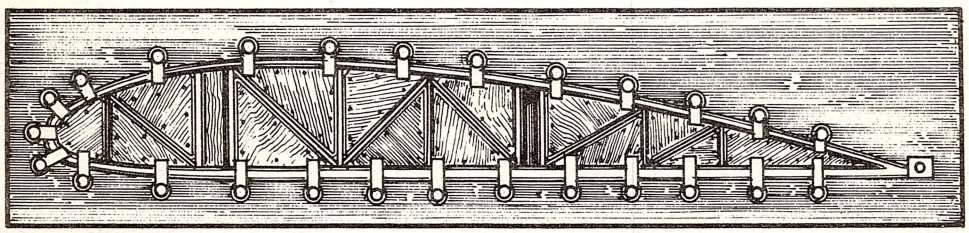


Figure 5

DETAIL OF STEEL RIB DRILLING JIG
FOR PREPARATION FOR RIVETING

pieces. The revolving hold down clamps are then screwed into place, and the drilling may be performed. Each rib will be drilled alike. The rivets will then be inserted, and the rib riveted with single shot riveters of low capacity for this light type of work. The cap strips are made in two pieces.

PATTERN MOCKUPS

In laying out the original patterns of the shape, dimensions, and the sizes of the shell plating or wing skin covering, the difficulty of laying out the original pattern is obvious. Any geometrical solid of revolution, such as is represented by the fuselage, is difficult to lay out in the flat sheet form from which the development may be made.

In the American plants, to speed production, the fuselage shape is built up in mock patterns shaped out of wood (half section). The outside is then covered with patterns, either of heavy paper or light gauge metal. This enables the rapid pattern layout of difficult curves and fairing lines. Obviously this method is the most accurate in developing the correct pattern. The same is sometimes done for the wing. From the master pattern the production sheets and sizes are developed. The master pattern is sent to the drafting room and the rivet hole spacing and other punchings are laid out, and then the sheets are ready to go into production.

In England, the commonly accepted method is to draw the side elevations of the plane or hull as it actually is. By the use of certain lines and developments, the actual sheet size is developed on the drafting layout. This elevation is the side elevation with all sheets shown flat. This method is just as correct as the other American method. However, it is subject to drafting inaccuracies that are difficult to track down in the shop until it shows up on the plane. Under normal circumstances the mockup pattern method is the best way of doing a rather difficult job. The same procedure would apply to hull designs of seaplanes.

Mock patterns may be either built of a light wooden formed structure or solidly built up in the half section. Wood is used because of its ability to be easily shaped as well as its cheapness.

BENDING OPERATION MATERIAL ALLOWANCES

In bending dural alloys or aluminum there is an empirical formula to go by. This formula has been figured for dural alloys and aluminum. By its use the proper amount of material may be determined mathematically beforehand in producing a specified part. This enables the correct amount of material to be used without excessive waste occurring.

Figure 6 illustrates the various requirements for bending. In bending operations reference must be made to the table of decimal equivalents of the inch. In working in gauges, the gauge number is discarded and every thickness is referred to in thousandths of an inch decimally. This is a very accurate way, and so the use of the decimal equivalents is imperative. The knowledge of how much material is required for every radius curvature is used very much in the design of fittings from flat patterns. The same procedure works for any radius.

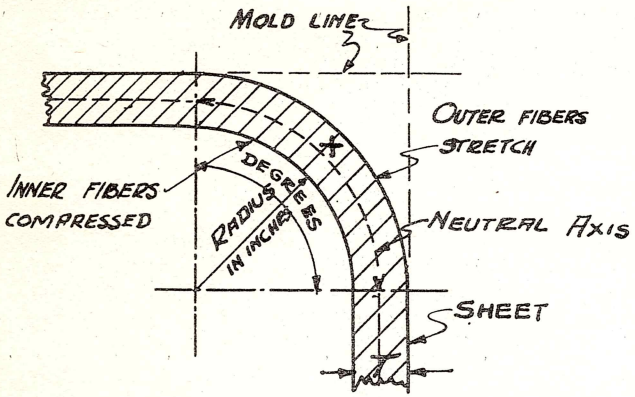


Figure 6

BEND DETAIL

The empirical formula for bending allowance of material:

.01743 x R plus (.0078 x T) = X T=Gauge thickness in decimals inches
R=Radius

Take the angle in degrees of bend required and multiply by the answer of the above formula. The answer will be in inches and decimal inches. This answer is the length of material that must be allowed for the bend over that required for the piece on each side of the mold line.

BENDING RADII FOR ALUMINUM ALLOY SHEETS

ALLOY	THICK-NESS .01-.02	THICK-NESS .021-.040	THICK-NESS .041-.064	THICK-NESS .065-.100	THICK-NESS .102-.375
51SO	0	0	0	A	
A17SO	0	0	0	A	A
B17SO	0	0	0	A	A
17SO	0	0	0	A	A
25SO	0	0	0	A	B
51SW	0	0	0	A	B
A17ST	0	0	A	B	C
B17ST	A	A	A	B	C
17S	A	A	A	B	C
25SW	B	B	B	C	C
17ST	B	B	C	D	D
25ST	E	C	D	D	E
51ST	E	E	E	E	E
C17ST	E	E	E	E	E

0: .2T to .5T C: 1.0T to 2.5T
B: .8T to 1.2T D: 1.5T to 3.5T
A: .5T to 1.2T E: Difficult bending From "Alcoa Co." Data

BENDS

Bending is a very precise operation. The minimum of bending and the larger the radii, the lower the production costs. Sharp bends or short bending radii require precise forming and greater handling. In large fuselage designs, to lower the cost of production, the sides should be of such gentle radius that they approach the flat sided form. The loss from flat sides on a long fuselage (similar to the DC-2 Douglas Airliner) is insignificant when compared with the saving in cost production.

Flat surfaces reduce the time and the labor for skinning operations. For cheapness, flat sheets should be used whenever possible or sheet radii of such gentle bend that the shell plating may be sprung into place by ordinary methods. Any radius means stretching. With a tapering fuselage form near the tail, the two directions of curves sometimes involves serious problems of forming. Short plates simplify the laying on of the plating near the empennage. Skinning costs are very great in large fuselages. A design with a minimum of special forming is economical, therefore, in production though a bit inefficient aerodynamically.

TOOL EDGE RADIUS

The radius of tool edges around which sheet stock is formed or bent is important. At no time should the minimum safe radius for the specific material be used. Tool edges should be true and straight. The radius is determined by the gauge and the material hardness.

In any bending operation the harder the material, the greater the minimum possible bending radius. If sharp bends are imperative either a re-design of the part will be the better way or an extrusion utilized. Extrusions can be had in 1/16" diameter on a 90 degree sharp angular bend.

In bending operations, the knowledge of the grain flow line direction is essential for correct practice in bending. The bending operation should be performed crosswise to the grain for maximum strength. The grain can be determined either optically or visually. When shearing up sheet stock for fabrications cognizance of this feature should be taken into account. Bending parallel to the grain weakens the structural efficiency of the individual piece of material.

In cutting lightening holes in small members and stiffeners, the holes should be staggered in sequence. This is done to enable the length of the grain between each hole to be doubled. This staggering of the holes increases the pitch distance between them. The stresses adjacent to the holes are spread over a larger area with a subsequent reduction in the unit stress from cutting the holes over a given area.

The following list of formed metal shapes have been utilized in various structures in aeronautic fabrication. These are preformed on forming machines, and then re-formed to suit the particular needs of the construction incorporating the same.

Figures 7 (1) and 7 (2) are used in riveted strip steel formed fuselages or dural, as the case may be.
The fairing section Figure 7 (3) is used on the fuselage sides.
The longitudinal stringer section is shown in Figure 7 (4).
Figure 7 (5) denotes the shape of a cap strip for ribs.
Figure 7 (6) is a Zee bar of any shape or size.
The corner reinforcing member is shown in Figure 7 (7) for a shell type of fuselage of rectangular dimension.
A section for wing ribs is shown in Figure 7 (8).
The cap strip used on many ribs is shown in Figure 7 (9).
Bulkheads are built from the section in Figure 7 (10).
Stringers are built from section shown in Figure 7 (11).
Cap strips for ribs may be made from the shapes in Figure 7 (12) when riveted back to back or used singly.
A rolled steel cap strip is shown in Figure 7 (13).
Figure 7 (14) is a bulkhead section.
The ordinary channel section is shown in Figure 7 (15).
A modified "J" section bulkhead shape is shown in Figure 7 (16).
Another modification of a bulkhead section is shown in Figure 7 (17). This is very strong when formed into shape.
Figure 7 (18) is another bulkhead or structural section.
Figure 7 (19) is a special shallow closed channel.
A special tee shape is shown in Figure 7 (20).
Figures 7 (21) and 7 (22) are the 90 degree angle shapes, both equal leg and unequal leg.
The "J" section standard shape for bulkheads is shown in Figure 7 (23). Used for stringers.
Figures 7 (24) and 7 (25) are modifications of Hall Sections. They are used for bulkheads, stringers, and the like.
Figure 7 (26) is another form of light gauge steel cap strip.

Any of the above shapes are available in dural, provided the rolling does not injure or fracture the metal by sharp forming or bending. Steel in light gauge has been widely used in construction of these forms.

POWER HAMMERS AND BUMPING

Power hammers are required in the production of convex and reflex curved fairings, or outer sections of certain parts of the shell plating. The power hammer is a pedestal tool of the heavy type. The pounding head operates up and down with a pounding die of the size and shape required. The machine is electrically driven and controlled, as to speed of operation, manually by the metal worker. Under the pounding die on the table of the machine is either a wooden female die or a rubber pad to allow the metal to form up or head up into place.

The male die has an adjustable chuck for a special die head of the rounded type. The operation of the power hammer is dependent upon the

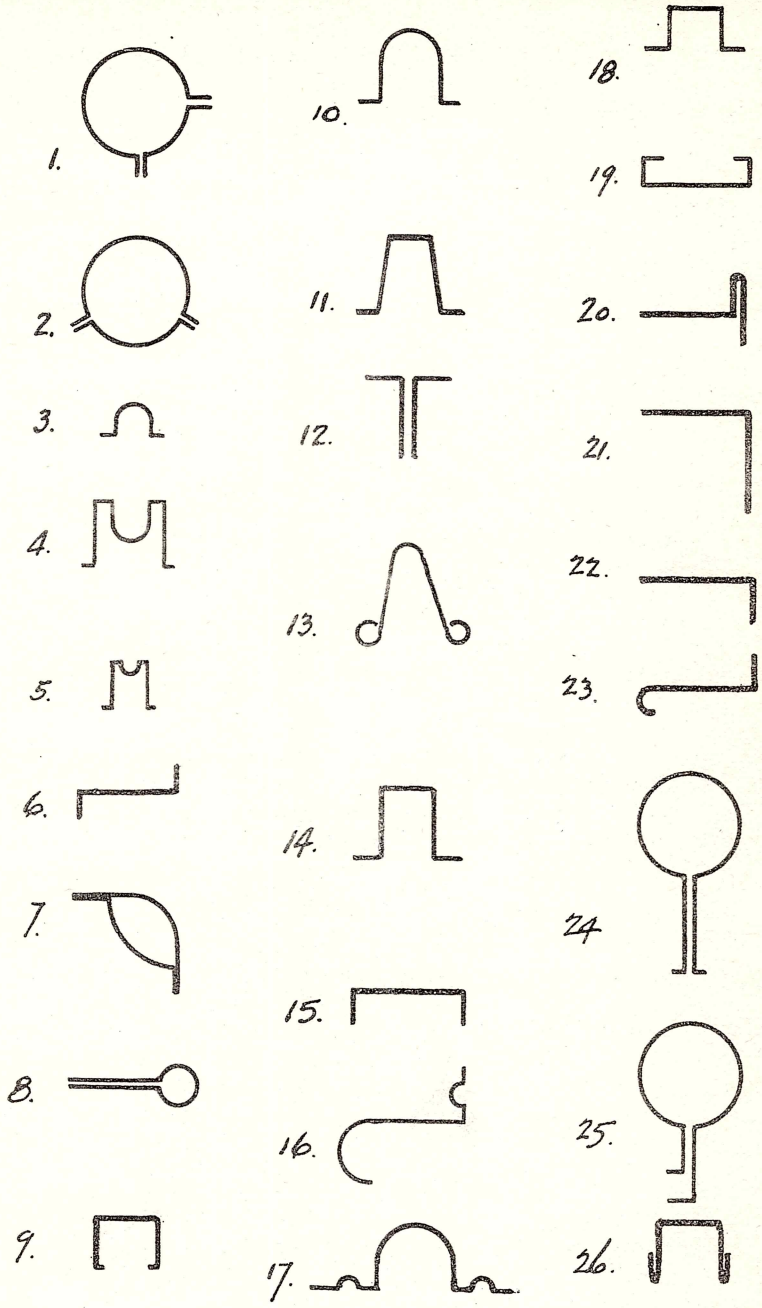


Figure 7

FORMED METAL SHAPES

skill and experience of the operator for good work. His ability to produce difficult bumped parts is determined by his ability and knowledge of forming soft metals, as in coppersmithing.

Hand bumping is still widely resorted to for light gauges and medium size parts. Hand bumping of the dural alloys must be confined to the "SO" variety. Any pounding of the metal has a tendency to harden up the same and make it brittle. Rubber hammers or wooden mallets are used in this work. Fillets are, in many instances, produced in this method. It is

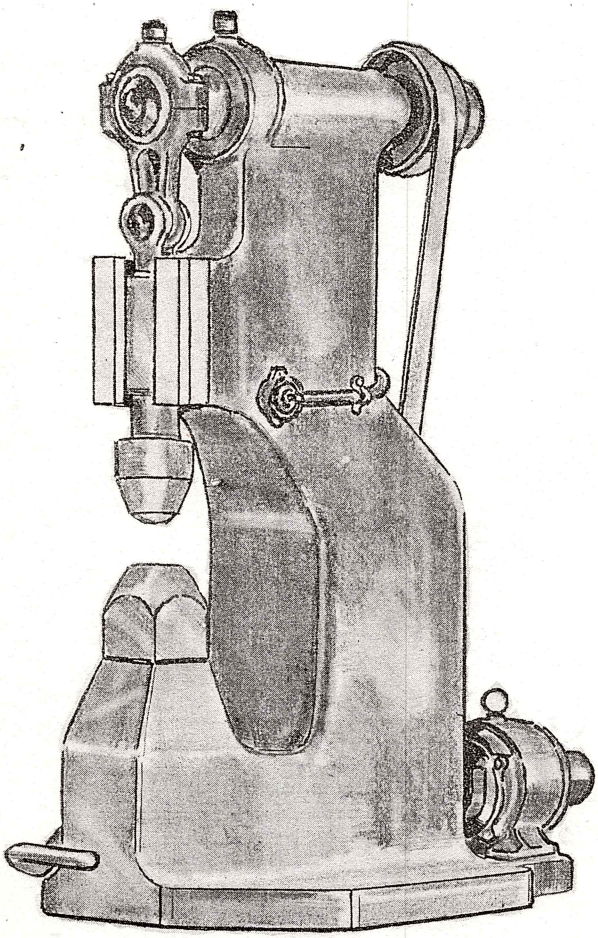


Figure 8

THE POWER HAMMER

important that the surface should not be scored or marred during this operation.

When the metal is too hard for cold working, heating and annealing the same for hand or machine bumping is resorted to in order to soften the material. If the metal annealed for bumping requires strength, the strength may be restored by heat treatment and aging. Bumping is the same as bending, and stretches and deforms the material. The same practice applies in regards to material here as in other practices.

For small simple pieces hand bumping is rapidly done. Where accuracy and uniformity are required wooden patterns must be used for hand bumping operations. For the heavier work forming dies and the power hammer are the best way.

WOODEN FORMERS

For cheapness in producing certain structural parts, such as bulkheads, wooden former patterns accurately machined from hard wood are sometimes employed. Strip dural is formed over the same by hand working and pounding. This method is limited to experimental production only. To work the metal in this way requires soft dural or aluminum with low strength. Working hardens the material, making it brittle. Heat treatment does not greatly improve the strength characteristics here. Solid bulkheads are sometimes flanged over a pattern in this method. Notwithstanding, successful fuselages have been built in this way.

THE STRENGTH OF RIVETED JOINTS

The basic principles of aircraft riveting are the same as in other forms of metal construction joints employing riveting. The rivets are so spaced in a properly designed joint that the forces acting on the individual rivet will not be greater than the estimated safe design value of the rivet in question. A rivet joint to be an efficient structure must be provided by a margin of safe design against crushing, shear, and tension forces.

In the design of a riveted joint the shear strength is the most important factor. Cross sectional area, the shearing strength of the material, and the possible lines along which the rivet tends to shear, all must be accounted for in the estimation of strength of the joint.

The size of holes for rivets must be slightly greater in diameter. This does not exceed, in good practice, five per cent of the shank diameter. A slight increment of rivet shearing strength is added after the rivet has been driven home, provided the hole is not oversize. If the rivet is subjected to tension forces a large hole under the head reduces the resistance of the rivet to holding. In no case should a rivet in a shell structure of light gauge be subjected to tension. The safe bearing strengths of rivets in dural structures depends on the material of the plates held together and the rivet material.

RIVETED JOINTS

The shell plating in a fuselage or a wing is fundamentally a tension member. When the plates are subjected to tension forces under the influence of the various conditions of flight loading, a shearing force is brought to bear upon the rivets of the joints, tending to cut them off. The simplest form of a riveted joint, and one which is most encountered in metal aircraft fabrication for the simple elements of the structure, is the single riveted lap joint.

Below is a practical example for a single riveted lap joint.

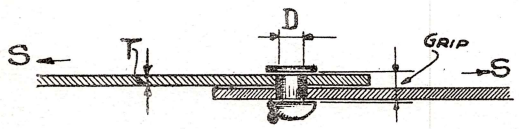


Figure 9

S = Tensile stress which is transmitted from one plate to the other by the agency of the rivet.
P = Pitch of the rivets (distance between shank centers)
S D = Shank Diameter of rivet.
T = Shell plating thickness.

The plate, when subjected to tension, will endeavor to tear apart on the section area (P-SD)T, whereas the rivet tends to shear off on the section area, 1/4 x 3.1416 x SD squared. An approximate estimation of the stress on the rivets and plates may be derived by solution of the above formulas. The shell plating will always have, as a solid plate, a higher factor of safety than that of the rivets. Hence, the need for rivets of good working qualities yet with strong shearing resistance. For a given tension in a shell plated structure the stresses in the rivets will be higher than that of the plates.

The total stress on one joint on the diametral plane of length equal to the pitch will be the unit stress per square inch, times the rivet pitch distance, multiplied by the diameter of the structure. Since each member of the plating carries half the load, the tension on each plate member will be one half of the value obtained in the formula for total stress in the diametral plane. This same value is substituted in determining the shear on the rivet shank.

The efficiency of a riveted joint is the ratio of the joint to that of the solid plate. For equal strength in tension and shear, the efficiency is $1 - \frac{SD}{P}$. This applies when a riveted butt joint is used with double rivets. It is assumed that the shear on the rivets is divided between each one. Therefore, the value of P will be itself divided by 2 for a double riveted joint; 3 for a triple riveted joint, and so on. When the joints have unequal tension, the efficiency of each must be estimated. For design purposes, the true efficiency will be the lesser of the value.

LENGTH OF RIVETS FOR VARIOUS GRIPS (ROUND HEAD)

GRIP	DIAMETER OF RIVET					HOLE DIA.
	1/4	5/16	3/8	7/16	1/2	1/32" GREATER
1/8	9/16	5/8	3/4			THAN RIVET
1/4		13/16	7/8	15/16	1-1/16	
3/8						
1/2						

LENGTH OF RIVETS FOR VARIOUS GRIPS (COUNTERSUNK FLAT HEAD)

GRIP	DIAMETER OF RIVET				
	1/4	5/16	3/8	7/16	1/2
1/4	3/4				
3/8	15/16	1	1-1/8	1-3/16	1-1/4
1/2	1-1/8	1-3/16	1-1/4	1-5/16	1-7/16
5/8	1-1/4	1-5/16	1-3/8	1-7/16	1-9/16
3/4	1-7/16	1-1/2	1-9/16	1-5/8	1-11/16
7/8	1-5/8	1-11/16	1-3/4	1-13/16	1-7/8
1	1-13/16	1-3/16	1-7/8	1-15/16	2

SAFE DESIGN VALUE OF ONE RIVET IN SINGLE SHEAR LBS. SQ. INCH.

		(Alloy)	(Cold Driven)		
SIZE	2S	3S	4S	17S	51SW
1/4	160	220	300	540	430
3/8	370	490	670	1220	980
1/2	650	860	1190	2160	1730
5/8	1010	1350	1860	3380	2710
3/4	1460	1940	2670		3900
7/8	1990	2660			
1					

SAFE BEARING DESIGN STRESSES FOR VARIOUS DRIVEN RIVETS.

	DRIVING PROCEDURE	SAFE BEARING DESIGN STRESS LBS. INCHES.
2S	Cold	7000 lbs. sq. inch
3S	Cold	9000 " " "
4S	Cold	14000 " " "
17S	Cold after quenching	26000 " " "
17ST		35000 " " "
A17ST		22000 " " "
24ST		44000 " " "

The most commonly used rivet in aircraft work is the 17S and driven in place immediately after quenching. A17S rivets are driven in the fully heat treated conditions while 24S rivets are driven cold after quenching.
On 2S, any temper, use 2S rivets.
On 3S0 and 4S0 use 3S rivets.

From Alcoa Co. Data.

SCREW AND RIVET GAUGES

SCREW GAUGES	INCHES
1	.073
2	.086
3	.099
4	.112
5	.125
6	.138
7	.151
8	.164
9	.177
10	.187
11	.203
12	.216
13	.229
14	.242
16	.268
18	.294
20	.312
22	.346
24	.372
30	.450
34	.505

RIVET GAUGES	INCHES
16	.065
15	.072
14	.083
13	.095
12	.109
11	.120
10	.134
9	.148
8	.165
7	.180
6	.203
5	.220
4	.238
3	.259
2	.284
1	.300
0	.340
00	.380
000	.425
0000	.454

RIVETING

Until the advent and perfection of fusion welding for thin shell structures, riveting the various components together will be the orthodox manner of joining the structure together. As we know it in present day construction, riveting is both expensive and overweight. It is, however, the best way that has been so far perfected in the methods of building monocoque structures. Rivet efficiencies vary directly as the type of joint, the pitch and diameter of the rivet shanks, and the shearing strength of the materials of the joint.

The majority of airplane riveting is done in the cold driven manner. This is because the rivets are small. Rivets are available in two kinds of rivet material. The low strength rivets, which are soft, are pure aluminum. For higher shearing strength, the rivet material is made of the higher strength dural alloys. When using rivets of the latter sort, they should be driven and headed up after heat treatment and aging. The type of rivets used depends on the kind of joint, the ratio of the head diameter to the shank diameter, and the shearing stresses. Rivet joints for maximum strength must always be presented in the shear condition.

The knowledge of the size of the rivet diameter for each individual joint is a matter of experience. For example, it would be incorrect to use a large diameter rivet for holding thin gauge sheets together. The extreme pressure to drive the rivet would cause the light sheets to buckle around the hole. Rivet shank diameter should rarely ever exceed 3 times the plate thickness. Where high bearing strength in shear is required, it would be better practice to use several rivets so disposed that the collective strength would be equal or greater than a large rivet of equivalent diameter. This again illustrates the principle of using low unit stresses per square inch in the thin shell type of structure. The multiplicity of small rivets equalize the stresses. Conversely, rivet shank diameter for strength must not be less than the thickness of the material being riveted together. This is the practice followed in aircraft construction of the monocoque and stressed skin types. The rivets should be of the same physical characteristics as the sheets being riveted. The use of a high number of small rivets helps to eliminate waviness produced by excessive rivet pressures required with large rivets.

Good practical shop practice requires that the edge distance of the joint intersection or overlapping must not be less than 2 times the rivet shank diameter. The minimum spacing is determined also by the driving conditions and clearances required for the driving tools. Where tightness is the first consideration, as in tanks and floats, the edge distance can be cut down to $1\frac{1}{2}$ times the rivet shank diameter.

Good shop practice requires that the rivet pitch should not be greater than 3 times the rivet shank diameter. In tension joints the governing factor is that the net area between the holes should not be too small. For joints, where strength is a minor consideration, the rivets may be pitched according to the sense of proportion of the designer. The rivets should not, in any case, be greater than the minimum strength requirements would allow.

The edge distance is measured from the center of the hole to the edge of the joint. The distance should be at least twice the diameter of

the rivet shank. If this distance is made smaller the edge of the sheet may be bulged. This weakens the material around the rivet hole, is unsightly, and decreases the bearing strength. It must be remembered that the shank pressures used in driving rivets run into very high values. If the edge distance is too small the adjacent material must stand some of this pressure. If the area is too small the unit stress is high, with bulging taking effect to relieve the metal.

Riveted joints for seaplane hulls, floats, or tanks must be tightly sealed together to be leakproof. Rivet edge spacing here is made less for this reason. The joints are caulked by a caulking tool. To aid the tightness of the joint special cement is at times used, which hardens up and forms a good tight joint.

Rivet holes are preferably first drilled and then reamed to size. The holes may be punched and reamed to size, but drilling is preferable. The efficiency of the joint depends on the size of the hole and other factors. In comparison to the solid material a riveted joint is always less efficient. Triple riveted seams develop nearly 90%, a double seam nearly 80%, and a single seam about 75% efficiency, to that of the solid material. This efficiency varies with the material, pitch, and quality of the work.

To increase the efficiency of the single lap joint, various methods have been used. The butt strap reinforcing reduces the stress on the rivet shanks, and a double butt strap further increases the efficiency. Butt straps unfortunately increase the weight. Where severe longitudinal bending is not encountered, the single lap joint is amply strong with its subsidiary strength members. Where high loads are imposed butt strapping is advisable.

Rivets are essentially pin members. The rivet holes and the rivet heads must be of such a design that a good formed up head is possible for clinching purposes. The preparation of the rivet hole is very important. It must be accurately drilled. The edges should not be burred, waved or elongated. In driving home the rivets, the material should be watched and strengthened against chances of waviness occurring.

Hand riveting is extensively employed where non-structural parts are used. The hole is drilled and reamed. The rivet is inserted and then driven home and headed over. The heading over tool is merely a die. An ordinary metal worker hammer is used to drive the head and clinch the same. The rivet is backed up with the dolly bar. This operation requires two men in cramped inaccessible places. One man drives the rivet and the other bucks it up, the latter being called a "buckerup".[11]

In heavier structural work, where enormous shank pressures are necessary, the squeeze riveter and the single shot riveter are extensively employed in cold riveting. The squeeze riveter is limited on large structures by the throat depth that would be required, and the impossibility of getting large tools inside and outside the structure. The single shot riveter is a single driving mechanism. It heads over and drives the rivet in one blow. The riveters of both the single shot and squeeze type are operated by compressed air. The single shot riveter requires two men. The squeeze riveter may be operated by one man.

11. In the parlance of the sheet metal or the riveting profession, the buckerup is the helper that holds the dolly bar while the rivet is being driven or clinched by the master mechanic. The buckerup is nothing more than a skilled helper.

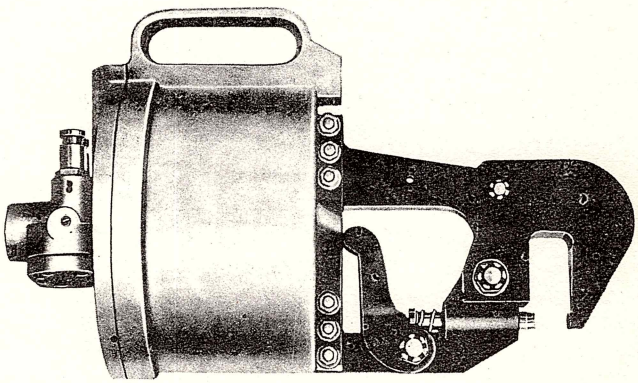
The squeeze riveter is used entirely in some classes of work where space limitations are not a hindrance. It is essentially a big yoke with ample throat clearance for the work. It is made in many types and sizes, some of which are hereinafter illustrated. These are made by the Chicago Pneumatic Tool Company.

The yoke of the squeeze riveter contains a driving head on one side. The other side has a heading up or female die. The yoke part driving mechanism is attached to an air line of 100 pounds pressure and controlled in operation by a valve in the handle. In operation the yoke is placed around the part to be riveted. The air is let into the pneumatic cylinder which, in turn, forces the driving mechanism against the shank of the rivet. The head of the rivet is tightly held in the die, slowly headed over, and clinched.

The air line to the machine is flexible. Essentially, the operation is the same as hand driving with the yoke acting as the dolly bar. The machine is automatically returned for another operation by the action of the powerful spring inside the cylinder. The controlling valve also releases the air pressure. The capacity of the machine is the rapidity in rivet insertion.

The machines vary in weight and capacity. The hand sizes range from 8½ to 13 pounds with various yoke sizes and dies. Beyond the rivet size of 7/16" shank diameter, the pressure developed by the squeeze machine is not powerful enough. For the larger shank rivets the pneumatic hammer is the best tool for driving in aircraft work.

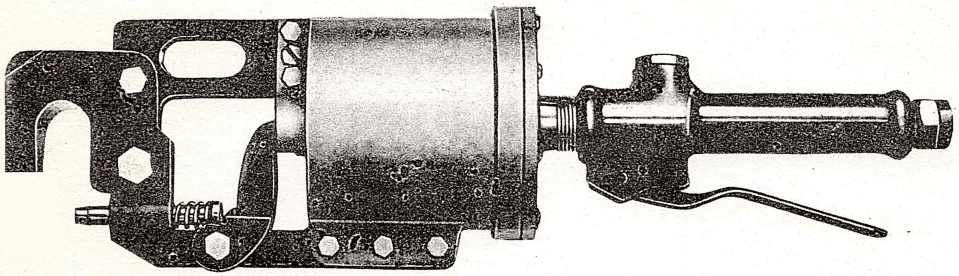
For squeeze riveting work only one man is required. The machines operate noiselessly. The shank pressures developed are all uniform, thus making for an efficient joint. The illustrations show the various types of machines used in American airplane construction. The number 1CP



No. 2 CP Squeeze Riveter

Figure 10

Courtesy Chicago Pneumatic Tool Co.



No. 1 CP Squeeze Riveter

Figure 11

Courtesy Chicago Pneumatic Tool Co.

squeeze riveter has a capacity for sizes of rivets shanks not exceeding 1/8", 5/32", or 3/16" aluminum rivets. The weight is $8\frac{1}{2}$ pounds. The number 2CP squeeze riveter weighs $16\frac{1}{2}$ pounds with capacities in shank diameter not exceeding 3/8".

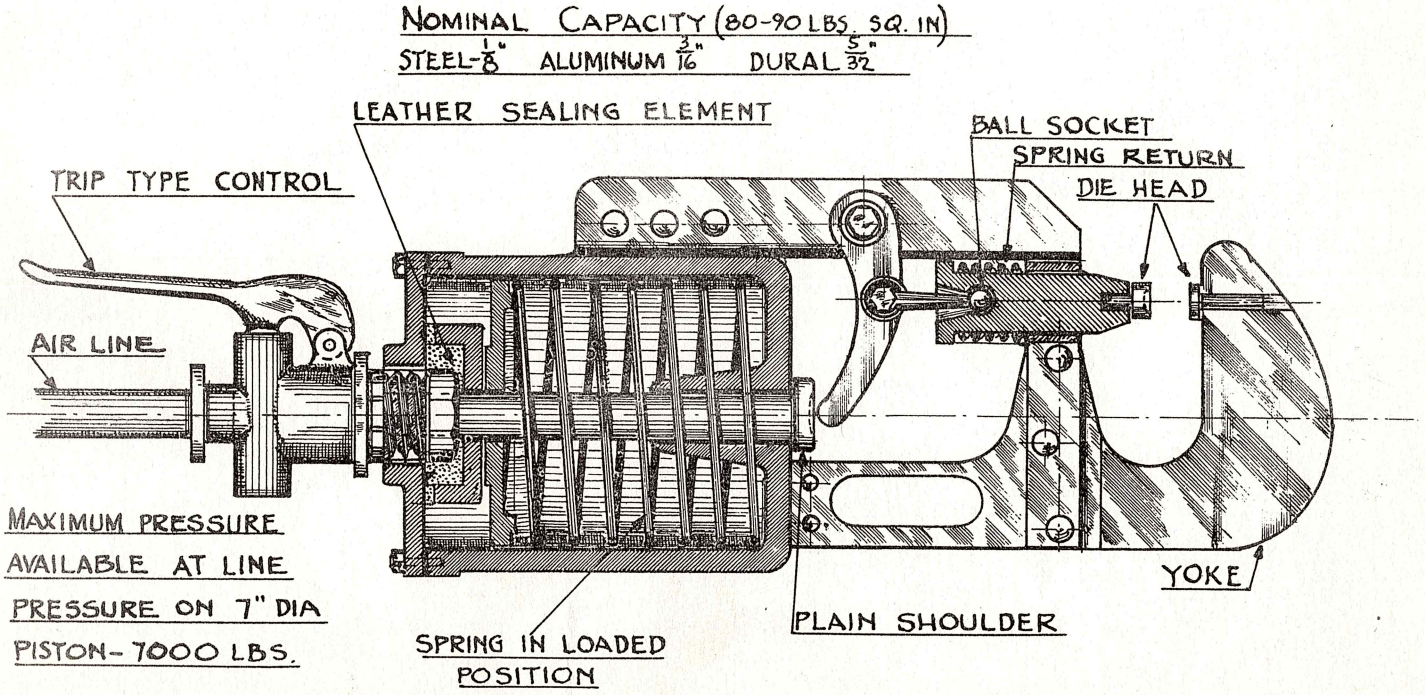
A squeeze riveter, similar to the American type, is shown herewith. This type is used in England for light work.

RIVETING

PRESSURES IN TONS REQUIRED TO DRIVE BUTTON HEAD RIVETS WITH A SQUEEZE RIVETER.

SHANK DIAMETER	2S	3S	4S	17S
1/4	6	7	7	10
3/8	14	15	16	24
1/2	25	27	31	
5/8	36	39		

17S rivets are driven immediately after quenching.



SQUEEZE RIVETER
WEIGHT 12 LBS

Figure 12

METAL SQUEEZE RIVETER

Squeeze riveters are manufactured in many different types and sizes. They all operate on the same principle. They may be pedestal mounted or hand operated. When they are too heavy for portability they are mounted on a sliding overhead trolley. In using these guns in any form the material is first clamped together tightly and temporarily bolted in place. To eliminate waviness, the rivets are clinched in an alternated sequence of spacing until the joint is completed.

Pneumatic riveters are a large cylinder with a driving ram or piston inside the cylinder. Air pressure against this ram operates the driving mechanism or hammer. This type of tool requires bucking up of some sort. The construction of the single shot riveter is similar. Pneumatic riveters or hammers operate at high driving velocities and are noisy. The driving mechanism of the hammer is returned by the action of a powerful spring. The single shot riveter is also reloaded in this manner. Pneumatic hammers operate from 3000 down to 800 blows per minute. For certain classes of work squeeze guns can be placed in a vise on a bench. This sometimes is a faster way of working certain structural pieces with rapidity.

Dimpling is a simple process of riveting whereby the sheet takes the shearing forces and the rivet merely acting as a pin member. One sheet is punched out with indentations, being the female, while the lapping sheet (male) is punched protrudingly and fitting into the indentations on the other sheet. The sheet then takes the shear stresses over a larger area than the rivet shank diameter. This type of construction allows the use of countersunk rivets. It is expensive and requires very great accuracy, and more labor than ordinary flush seam riveting. In this country it is patented by Charles Ward Hall. Abroad, the principle is known as the DeBergue system of joints, being used there for tanks and hull structures.

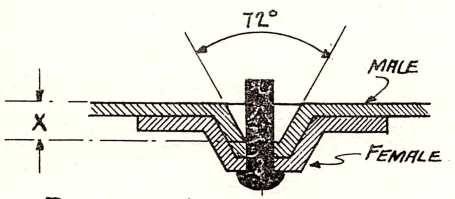


Figure 13

TYPICAL DIMPLED JOINT
Courtesy Alcoa Co.

SQUEEZE RIVETING

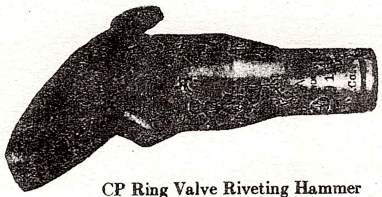
The various tools for aircraft riveting production are many and varied in their uses and adaptabilities. The Chicago Pneumatic Tool Company's line is very extensive and covers the field. The various tools are illustrated in Figures 14 to 23. A brief description is given of each.

The CP valve riveting hammer is a lightweight tool for light riveting operations and drives up to 1/8" dural rivets. See Figure 14.

The riveting hammer, with a pistol grip and sensitive control, is another tool for lightweight work in tight places. The tool is shown in Figure 15.

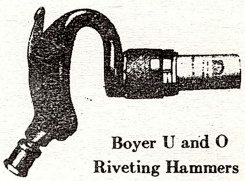
The single shot riveter, shown in Figure 16, is capable of driving up to 3/16" dural rivets with a single blow, when backed up by a suitable dolly, and eliminates strains on the surrounding metal plating.

The CP portable compression riveter is shown in Figure 17, and is capable of squeezing rivets of medium size for the skin of the wing and the fuselage. The yoke is adjustable up to the capacity of the machine.



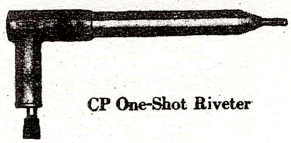
CP Ring Valve Riveting Hammer
Type UU-RV

Figure 14
Courtesy Chicago Pneumatic Tool Co.



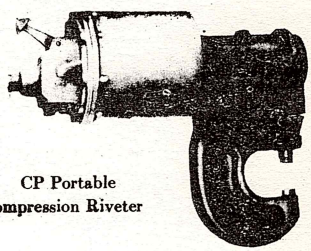
Boyer U and O
Riveting Hammers

Figure 15
Courtesy Chicago Pneumatic Tool Co.



CP One-Shot Riveter

Figure 16
Courtesy Chicago Pneumatic Tool Co.



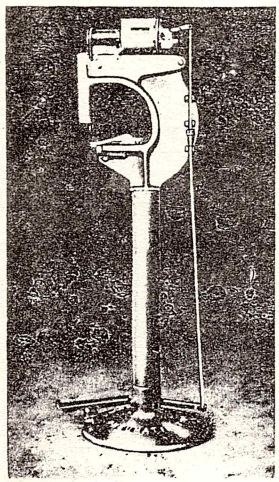
CP Portable
Compression Riveter

Figure 17
Courtesy Chicago Pneumatic Tool Co.

The stationary compression riveter is available for pedestal mounting. This is furnished with a foot treadle control and various power units. The device is shown in Figure 18.

The CP baby riveting hammer is designed for cramped places where the squeeze gun cannot operate. The machine does the work by a hammering action and requires a buckerup. The hammer is shown in Figure 19.

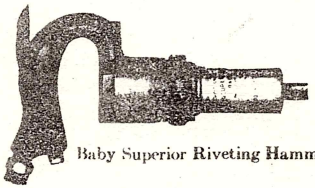
The CP portable shackle press is another tool that has wide application for driving pins and shackle bolts. It is a one man tool, operated by compressed air, and controlled by a special valve. The machine is shown in Figure 20.



CP Stationary Compression Riveter

Figure 18

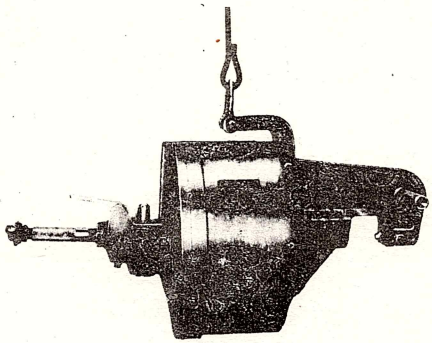
Courtesy Chicago Pneumatic Tool Co.



Baby Superior Riveting Hammer

Figure 19

Courtesy Chicago Pneumatic Tool Co.

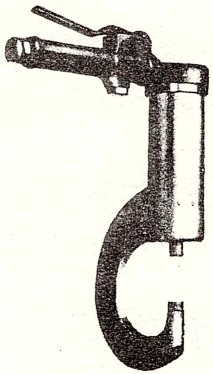


CP Portable Press

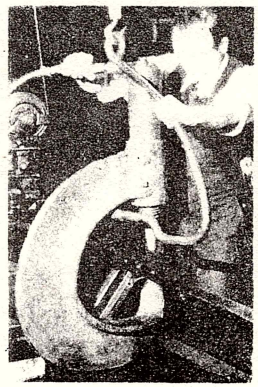
Figure 20

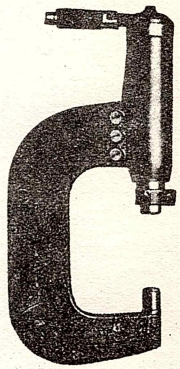
Courtesy Chicago Pneumatic Tool Co.

Other types of riveting tools for heavier aircraft work are shown in Figures 21 to 23 inclusive. These machines are made by the Chicago Pneumatic Tool Company who produce the most extensive line of riveting devices for aircraft in the U. S. A.



RV-1X Yoke Riveter
with Standard Throttle Handle





CP-60 Yoke Riveter

No. Type	Capacity Rivets (Hot) Inches	Bore and Stroke Inches	Blows per Minute	Net Weight with Yoke, Pounds
*RV-1X	1/4	13/16 x 1 1/2	2800	21
†RV-2	1/4	15/16 x 2	2760	30
†CP-2X	3/8	1 1/8 x 2 1/2	2400	45
†CP-60	7/8	1-1/16 x 6	1340	90
†CP-80	1 1/8	1-1/16 x 8	1050	92
†CP-90	1 1/4	1-1/16 x 9	910	94
CP-80X	1 3/8	1-3/16 x 8	950	130 – 190

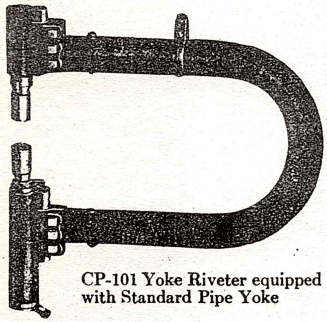
Figure 21

Courtesy Chicago Pneumatic Tool Co.

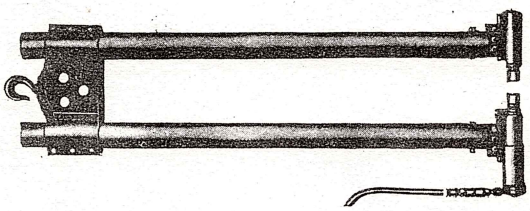
The riveters shown in Figure 21 are a yoke type employing the hammer method of heading up the rivet. Riveters of this sort are used for heavy rivet driving. They are controlled by a throttle valve on the air line.

The model CP-100 and the CP-101 yoke type riveters can be equipped with a U pipe yoke having a 15 inch gap and 30 inch reach. A special pipe yoke may also be used. The specifications given above are for the machine when equipped with a U pipe yoke.

These riveters are of the hammer type.



CP-101 Yoke Riveter equipped with Standard Pipe Yoke



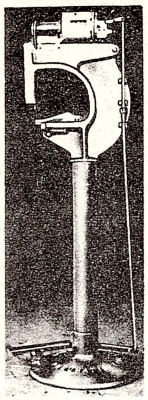
CP-101 Riveter with Special Pipe Yoke as made when an extra long reach is required. Suspension clamp not furnished with riveter. It is readily made in any blacksmith shop if required.

Reach of Yoke Inches	Gap Inches	Weight Pounds
30	15	185
48	15	209
60	15	562
72	15	584
84	15	625
96	15	667
108	15	709

No. Type	Capacity Rivets Inches	Bore and Stroke Inches	Blows per Minute	Net Weight with Yoke, Pounds
*CP-100	1¼	1¾ x 3⅞	1100	233
*CP-101	1½	1¾ x 6	775	256

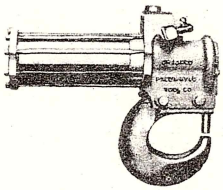
Figure 22

Courtesy Chicago Pneumatic Tool Co.

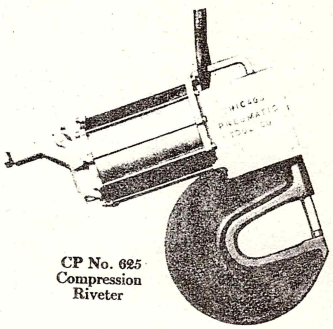


CP Compression Riveter with Stand

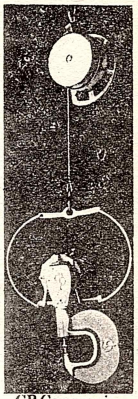
CP No. 1 Aero One-Shot Riveter



CP No. 200 Compression Riveter



CP No. 625 Compression Riveter



CP Compression Riveter with CP Balancer

CP Compression and One-Shot Riveters

LIGHT, powerful, compact machines of particular value in the manufacture of airplanes and light sheet-metal products. The operation is a "squeeze" which drives tight, uniform rivets and eliminates stresses and strains on the surrounding metal. A variety of interchangeable yokes can be furnished, including a swivel-type yoke and clamping device. All models except the One-Shot, No. 1 Aero, No. 1, No. 2 and No. 1000, can be furnished with stand as illustrated.

No. Type	Capacity	NET WEIGHT, LBS.	
		Without Yoke	With Yoke
No. 1 Compression Riveter	1/8" Steel Rivets 5/32" Duralumin Rivets 5/16" Aluminum Rivets	8	....
No. 2 Compression Riveter	3/16" Steel Rivets 3/16" Duralumin Rivets 3/8" Aluminum Rivets	16½	....
No. 200 Compression Riveter	1/8" Duralumin Rivets 1/8" Soft Steel Rivets	....	5¼
No. 350 Compression Riveter	5/32" Duralumin Rivets 5/32" Soft Steel Rivets	10½	....
No. 450 Compression Riveter	3/16" Duralumin Rivets 3/16" Steel Rivets 3/16" Aluminum Rivets	16	....
No. 625 Compression Riveter	1/4" Duralumin Rivets 1/4" Cold Iron Rivets	22½	....
No. 1000 Compression Riveter	3/8" Cold Iron Rivets	152	....
CP One Shot	3/16" Duralumin Rivets	4 lb. 5 oz.	
CP No. 1 Aero	1/8" Duralumin Rivets	3 lb. 5 0z.	

Figure 23

Courtesy Chicago Pneumatic Tool Co.

RIVET DRIVING PROCEDURE*

The driving procedure for aluminum rivets does not deviate greatly from general practice encountered in mechanical construction in other forms.

The soft rivets, 2S, 3S, and 4S should be driven cold as received from the stock bins. They may be stored for an indefinite period without impairing their strength or workability.

The next hardest grade of rivets is the 17S material. These rivets must be heat treated to produce the maximum strength properties in the finished rivet. The rivets are subjected to a temperature ranging from 930 to 950 degrees Fahrenheit for five to thirty minutes. After this they are immediately quenched in cold water. They must be driven home into the structure within two hours after quenching. If allowed to age more than two hours they are too hard to drive. They reach their maximum strength at room temperature in about four days.

To retard aging after heat treatment rivets are kept at low temperatures close to 32 degrees Fahrenheit immediately after quenching. They then remain usable for about 36 hours longer. Still lower temperatures will extend this softened period indefinitely. In production work, the rivets are taken from a refrigerated container. The workmen never take more than a 15 minute supply at once.

Rivets of 17ST material must be re-heat treated before driving. Unless this is done they are too hard to drive and head up. The rivets of 51SW material alloy may be driven cold in the small sizes. These rivets harden very slowly.For heat treatment they require a higher temperature.

The practice of spinning over the heads of rivets is not satisfactory for most methods of joints. Of course spun rivets with long shanks have their uses. In heading over rivets of long shank dimensions, the ordinary driving method is better. Spinning twists the rivet shank or the material around the hole. In any case, in heading over long rivets care must be taken not to collapse the shank under pounding,since in any rivet operation the head becomes harder than the rest of the shank under the action of tooling.

Hot driving is not used extensively in the light monocoque structure assembly. Hot driving is confined to rivet sizes over 1/2" shank diameter. Since these sizes are seldom used, hot driving of rivets is the exception. If rivets are to be driven while hot they should be inserted quickly and driven home. Hot riveting alters the area around the hole, because of the high heat conductivity of dural alloys. The rivet is cooled quickly and hardened. The sheet material is softened by the heat. This causes unsatisfactory joint stresses.

* From "Alcoa Co." Data.

Hollow rivets for light weight work are squeezed by small hand tools. A hollow rivet simply acts as a pin member. Rivets of this sort are not used where high clinching forces are required. These rivets are unsatisfactory for shearing stresses and fail very quickly in this condition. Rivets of the hollow type are used for light structural pieces,

wing ribs where the unit stresses are small, and as pure lightweight pin members.

The pressure required to drive aluminum alloy rivets depends on the diameter of the shank area, the material of the rivet, and the type of head. These are further dependent upon the room temperature. The driving force required varies roughly as the square of the diameter of the finished driven head. That is why small rivets drive proportionately easier. To reduce driving pressures, therefore, and where appearance is not to be considered, button head rivets are used in preference to other types of heads for the same shank diameter.

Any form of riveting tool or device for heading over aluminum rivets should exert enough pressure so the head of the rivet is not hardened before the shank is compressed. Squeeze riveters assure properly upset shanks and good centering of the heads. An eccentric head setting reduces the clinching strength of the rivets enormously. For hand driving, a series of heavy blows with a heavy hammer should be used. The heading up tool or rivet set should be highly polished so the metal may flow easily during the forming of the head.

The size of the rivet holes to some extent,determines the efficiency of the driven rivet. If the holes are oversize the rivet will have a tendency to get out of vertical alignment. A loose fit is harder to hold in the tool and allows eccentricity of the head alignment. Cold rivets should be inserted quickly and easily.

The length of the rivet grip for forming of the head depends on the grip or the total thickness of the joints of the metal sheets, and the rivet hole clearances. The actual length is best determined by experience. The table given is an approximate estimate for rivets of 17S in 17ST plate. The best method advocated is to make several tests and trials. Over length rivets are better than under length rivets.

In determining generally the rivet alloy to use with various kinds of sheet material, a great many factors must be considered. A hard rivet alloy should not be used to hold two soft sheets together. The maximum strength in shear would not be proportionate. The strength of the rivet is governed by its bearing value in the material it joins.

In any case it is poor practice to have too much dissimilarity between the physical characteristics of the alloy of the rivet and the sheet material that it joins together. It is most advantageous to have the two elements of very close physical properties. Conversely, a softer rivet will not be a good pin member in shear in a hard material if the stresses imposed on the joint are high.

In aircraft work the most commonly used rivet is of 17S alloy driven cold. The 24S alloy rivets are also driven cold quickly after quenching. When using Alclad alloy sheeting 17ST, 24ST rivets can be used. The Alclad alloy coating electrolytically protects the heads of the rivets as it does not cut the edges of the sheet. In riveting up Alclad sheets, the heading die must be held vertical to the surface. The depression in the heading up die must be of such a size that it bears around the base. Any eccentricity invariably produces a poor rivet head. If the rivet is damaged the Alclad coating will likewise suffer, thus offering a chance for corrosive attacks to begin under the coating of Alclad. Needless to say,any riveting gun or tool must be aligned vertical to the rivet shank at all times.

GENERAL MACHINE OPERATIONS IN AIRCRAFT MANUFACTURE*

Dural alloys are easily machined. They arrive at the machine shop in forms of castings, forgings or the raw billet stock to be manufactured into finished parts. In machining of dural on the lathe tools, there is a slight change in the cutting edges of the cutting tool. For lathe cutting the tool edge should be ground with a greater side rake than for steel. The round nosed tool is used for roughing and finishing. For finishing, the edge must be smooth and free of burrs. The tool is set higher on the work center than the same would be in machining steel. This higher setting eliminates clogging from the chips. The chips are always harder and scratch the finished part. The diameter of the part to be machined determines the cutting speed as does the alloy and the cut to be made.

Side cutting and planing operations required for special parts in plane construction are easily accomplished on dural or aluminum. Special tools, with special side rakes and cutting faces, must be used. The material must not be allowed to heat excessively. Dural planes easily. Planing, while expensive, sometimes is a better method than forming up a special part out of flat stock.

TAPPING AND THREADING

In dural or aluminum, tapping is a precise operation. The material is soft and, if threaded improperly, can be easily stripped. The tapped holes should always be bored a trifle undersize. The gripping power of the male thread is then increased. Threads cut in aluminum are either of the coarse machine type or American National Thread, which is used by the A.S.M.E. and the S.A.E. in standard practice.

SAWING

Sawing is essentially a rapid production operation in thick sheet stock. The saws utilized for this work all must have a special rake to the cutting teeth and the pitch of the teeth. The saws must have a positive rake. The material must be clamped down tightly while being cut, and fed slowly to prevent high localized heating with its alteration of the material characteristics.

Band saws operate up to 5000 f.p.m., while table cutting saws run up to 10,000 f.p.m.** The machines must be firmly bedded down to prevent vibration and ragged cuts. The material must be fed slowly. Cuts in the aluminum alloys group must be small. A liberal application of cutting compound must be used for cooling and to retain the strength characteristics.

*From "Alcoa Co." Data.

** f.p.m. is an abbreviation for "feet per minute".

Broaching and shaping are machine operations used in certain parts of production of structural parts of a plane. The process is the same as that done in steel except that the cutting tools must have special edges. The parts, after being machined, may be heat treated and aged.

FINISH

Any form of good aircraft metal construction should be produced with a good surface finish. The finish should be lustrous and highly polished. The purpose of finishing is to add a degree of protection from the corrosive effects of the elements when exposed.

For exterior surfaces Alclad sheeting is a good way to combat the action of corrosive agents. Another widely used method of getting a good finish on manufactured parts is to anodically treat the parts desired. Anodic treatment is an electrolytic process. It is essentially the same as coating the surfaces with a layer of aluminum oxide adhering to the surface. This treatment must be completed before riveting the various parts together. It is limited to individual parts.

To prevent electrolytic effects dissimilar metals should either be plated strongly or separated by an insulator sheet. Cadmium plating helps reduce electrolytic effects. Any form of plating is subject to vibration and the outer film, if it is not elastic,may peel off in time. Cadmium plating is used for most fittings as a finish. Fittings and metal hulls subject to salt water corrosion are further protected by suitable varnishes.

For interior parts and control members, chromium plating presents a good appearance and satisfactory surface protection.It does not corrode. It is accomplished electrolytically over a base plating of copper.

Ordinary machine parts are best finished to varying degrees of polish by the ordinary emery cloth and a polishing compound. They can be polished to a high degree of smoothness. Certain parts may also be Udylited or lacquered heavily. In all cases, finishing is a very important operation in the manufacture of aircraft parts. Rivets may be purchased with polished or unpolished heads.Sheet dural or aluminum is also available in varying degrees of polishing as the occasion requires.

BEADING

For certain light structural parts of thin gauge, aluminum raw edges are finished either by bending back, flanging, or beading. This operation is limited in its scope as to gauge. It stretches the metal excessively. Beading is done with a small pedestal or bench machine operating on the principle of a roller die.

LIGHTENING HOLES

In the ultimate attempt to gain a low weight to strength ratio, a certain elimination of "dead" structural weight is advisable. This material is determined by experience as to when, where, and how much may be cut away from the structure. Lightening holes may be either pressed on dies or cut with circular cutters. They are drilled in small longeron sections.

Under certain conditions a solid section actually is less strong than a section with lightening holes cut at specific intervals. This is possible, because the area of the high skin stresses around each hole contributes to the strength of the specimen.

Lightening holes are also cut to aid the bending and forming of certain difficult parts, such as bulkheads and stringers. Cutting the material away internally on the web in a bulkhead reduces the effort to bend the same, and to do so more easily.

STRUT ENDS AND JOINTS

This group of items is very important. These ends or joints in struts are under tension and compression forces in flight conditions constantly. The usual method is to use a machined dural forging in a tubular strut end held with hollow pin type rivets. This method is very strong as a joint, provided that the axes of each joint member intersect. This avoids eccentricity of moments on the joint.

On most joints the clevis type of end connection is used. The efficiency of a fitting is similar as a joint. Strut intersections are made in the same way. In hollow tubes, fillers may be used at the ends to help absorb high end loadings.

METAL SPAR PRODUCTION

As yet, few spars are made under what may be termed mass production. This condition is imposed by the small amount of airplane production orders going through the factories at one time. The wing spar is one of the most important elements of the plane structure. No expense should be spared in labor or design to produce the best and the lightest for strength. Production in quantity necessitates rigid inspections after completion for accuracy and straightness. Samples from time to time must be subjected to breakdown tests.

The ideal spar is of metal and of simple design. Simple spars may cost less to build, but when subsidiary members are required to brace the simple spar in the structure, the cost will be as much as perhaps a spar of more complicated construction.

The box type of spar is the easiest to build in production. The majority of wings are built around either a box or "I" section spar. In good design the allocation of the rivets should be such that it may be riveted quickly in flat jigs without inside riveting being required. Simple spar parts can be built on the drop brake cheaply. The points to consider are the method of jointing, the end fittings, and splices. These accessory parts must also bear an economy in production.

The strength of a spar in bending depends on the distance of each flange top and bottom from the neutral axis. The neutral axis lies close to the center of the distance between the top and bottom of the web, depending on the disposition of the material. The web is the shear member. Webs in fabricated spars are of light gauges, stiffened at intervals. In spar design the cost of the stiffening members must be accounted for, both in labor and manufacture of the same. A simple spar, for example, with many stiffeners may cost as much as a heavier spar with few stiffeners. Here, the experience of the designer must be utilized to determine the

most efficient structure from a structural standpoint, and the most economical in production.

In various forms of wing construction the weight of the spars in proportion to the wing weight varies directly with the number of the same employed in the airfoil. It might also be added that the labor cost is increased as the spar number is increased. These are points to consider in the light of the competitive conditions in the aircraft industry.

BULKHEAD CONSTRUCTION

Bulkheads, in any form, are costly pieces of the airplane structure to manufacture. The great variation in size and design in a single fuselage accounts for this. Production of bulkheads cheaply is impossible unless recourse is made to produce the same in small parts. Each small part is then riveted together in a jigged form and completed.

A bulkhead in channel form of large dimensions and of good design is the bulkhead used in the Douglas DC-2 Airliner. This bulkhead is made of several sections riveted together. The bulkhead uses a minimum of material; little forming work is required; it is strong; and it is efficient. For economical bulkhead construction the cost of splice plates is less than if the whole affair was made in or from one piece of sheet stock.

There has been expended much effort to produce cheap fuselage bulkheadings, but at present the problem is far from being solved cheaply with material costing as much as it does today. Round fuselages are the strongest. A round bulkhead requires forming on a special bending machine or else pressed out. The best method under such circumstances is to produce it in segments and rivet the same together. The wastage of material in one piece bulkheads offsets the other costs. Rolling stretches the metal, requiring straightening and at best is a difficult process.

For weight to strength basis of comparison, one bulkhead is not any more attractive than another. The costs will be very closely related. One piece bulkheads, while being the ultimate ideal, at present are prohibitive.

STIFFENER MEMBERS

These subsidiary members of the fuselage or wing are very important. Stiffener sections assume a myriad of shapes, more or less being modifications of the channel, the angle, or the circular bulb sections. The angle stiffener is the cheapest and the lightest. The channel is heavier, but it is stronger.

Stiffeners are built into the structure integrally, be it fuselage or wing. They are lightened to save weight. In certain forms of construction they are simply riveted to the skin. To do this they must be straight so the skin will not have a chance to incline toward waviness. The stiffener must be so secured in the structure that it must resist

12. As spoken of here pitch simply means the spacing. A rivet pitch of 3 inches would mean the center to center distance of each hole was three inches apart. Pitch is also used for other airplane terms. In metal work the pitch means spacing.

any local form of bending. Extrusions and rollings are used in the manufacture of stiffener sections. The lighter the structure, the greater the need for stiffeners and the closer the pitch[12] of the same.

WELDING

Aluminum is capable of being welded with the gas torch. In reference to sheets, this applies where the gauges are thick enough to stand welding. In welding aluminum the usual welding apparatus is used. The correct tip and torch flame for any kind of work is a matter of experience and handling of the welded parts. The smaller the gauge, the smaller the tip and less the size of the flame. For joining aluminum parts the fusion method is used almost entirely. Spot welding and electric arc welding are coming into slow but general use.

The procedure for welding is the same for any other material. The flux is the agent that cleans the part to be welded. Flux removes the outer film of oxidation. Welding rod or wire is used for the softer aluminum and its alloys. It is pure aluminum. For special alloys the same rod is used as the alloy to be welded.

In welding it must be remembered that the coefficient of expansion per inch is very high on aluminum parts. The work must be clamped down tightly so that the part may not be spoiled by distortion. Cracks can develop easily in any aluminum weld, because of high conductivity of the heat and the contraction when cooling. Extremes in either of these conditions will result in a faulty weld.

Welding is used for certain non-structural parts, such as gas tanks, fairings, cowls, and the like. When welding light gauges the usual method is to slightly flange each edge to be joined. In welding heavy stock the usual Vee joint seam is first made and the crevice filled with welding rod.

To facilitate production certain forms of tables or jigs should be used. The best method for welding a casting is to mount the casting on a pedestal mounting so that it can be rotated into any position. This enables the operator to quickly weld the casting in any position. A long flat metal table with hold down clamps is best used to advantage for flat sheets to be welded. Buckling must be accounted for. When cool, the material should be straightened after welding.

In the present technique of the art, welds are only used for non-structural parts. Welds, in tension, are unsafe joints. The tensile strength of a welded joint is very low. It is about half that of the original strength of the material. Rapid welding reduces the danger of overheating and annealing. The actual welding operation, handling, puddling, flame and tip size is a matter of welding judgment and experience.

Arc welding of dural alloys is the same as welding other metals. The equipment may be portable. Welding rod of the same material as the welded part is used, being about 1/8" diameter of the coated variety. The arc must be short in length. Arc welding reduces buckling to a minimum. It allows speedier work. Arc welding is only suitable on heavy gauges. It requires 300 amperes current at 60 volts potential. The flux acts as a stabilizing agent during welding, and must be removed by a mild acid bath. At best, the process is limited. In Europe arc and spot welding electrically holds promise of being perfected shortly.

SPOT WELDING

Spot welding has not been extensively used in the United States in aircraft. In France much progress has been made in this direction on wing spars as well as other kindred parts of the structure. The advantage is obvious over the cost of riveting. The weight of the structure is also lighter, because the joint lappings may be less and the weight of the rivet heads is saved.

The secret lies in the short current time and the mechanical pressure applied. The material welds at 550 degrees above the critical temperature. There is only small local overheating, because of the high heat conductivity. The cooling of the electrode and the material to be welded is done artificially.

The parts to be joined together are placed in the usual pedestal type of welding machine between the electrodes. They are forced together mechanically, under heavy pressure, and then allowed to part slightly. The current is applied, and then the plates are squeezed together tightly again and removed. Welds performed in this manner compare favorably with rivet strengths pitched on the same distance.

This type of welding requires special electrodes. Very high electrical currents are necessary, because of the conductivity of aluminum. The pressures joining the two pieces of metal to be welded will be less than other materials. Materials welded by the resistance method weld and join easily when in the molten or plastic state. The welding, for uniformity, should be done automatically. The closeness of the plastic temperature and the melting temperature require that precise control of the current and pressure be maintained. The diameter of the area welded by spotting should be the same as a corresponding rivet area, and pitched similarly.

SHOT WELDING

The process of shot welding has been under development by the Edward G. Budd Body Co. for several years. This process is used in the welding of stainless steel airplane structures. The process has not found very wide use in commercial aircraft production in the U.S.A. On the contrary this process has been widely utilized in the airplane fabrication overseas. The Soviet Government of Russia have use of this process under license.

The shot welding machine is portable. The small size and the adaptability of welding easily and quickly, in inaccessible places, makes the process attractive to rapid production. The principle is based on the resistance welding method. A special welding tong is used with electrodes gripping the pieces to be welded together tightly. The advantage of this form of welding is its freedom from corona effects, and the reduction in the area around the weld which is ordinarily affected in the common spot welding method. A special recorder machine supplies a visual and audible record of each weld as it is made. This enables defective welds to be spotted easily and quickly by the inspector of the finished work.

In the process of shot welding the diameter of the fused slug of material has a definite relation to the thickness of the sheets to be

welded. The shot weld itself should not exceed in diameter three thicknesses dimension of the sheets to be welded. The strength of the current and the relation of the time determines the strength of the shot weld. The heat of the weld is very low in temperature. Shot welding is attractive to thin gauge welding, because the distortion caused by the weld is practically nil.

The welding gun is composed of two tongs. Each tong has a copper electrode with a tapered point. The device is so constructed that the gripping produces pressure on the sheets to be welded, squeezing them together. The duration of the current flow is instantaneous. The weld is similar to a rivet joint.

A good shot welding operator can join up ten shot welds per minute. On long runs, and where the spacing is punch marked, quicker welding may be accomplished. This process has the advantage of being in light structures the solution to rapid production. The shot welding process is licensed for aircraft construction in Russia, France, and Italy. Metal airplane spars using this process of construction have been produced by aircraft concerns in these European countries. The weld does not corrode, and the strength in shearing is nearly the same as rivets. Its use at present is confined to steel only. In the future other materials may be welded by this method. The pitch of the welds would be the same as the equivalent for rivets.

NIBBLERS

The nibbler is a die cutting machine electrically operated. The machine is pedestal mounted for various operations. The nibbler comprises a cutting die working up and down rapidly in the vertical plane. The machine is used for cutting the flat patterns for fittings before they are formed up. The machine is capable of cutting irregular shapes in any form up to 12 gauge. The principle the machine operates on is the cutting die tears away small pieces rapidly and so eliminates lengthy cutting operations by ordinary methods.

Any type of aircraft material may be cut easily. Dural or aluminum requires a special cutting rake on the die. The machine may also be converted into a braking tool for light strip stock, if desired, by changing the die formers. The die is adjustable, and can produce angle sections from flat stock by a series of rapid bends as the flat material is fed along. Machines of this kind lower production costs, and can be operated by semi-skilled labor.

HAND TOOLS

The modern airplane is essentially a structure that is being built more and more with a diminution of hand labor operations. Yet for certain operations the workman cannot dispense with hand tools. A familiar knowledge of the same will be of good value to the novice.

For polishing, sanding, drilling, or grinding, the portable flexible shaft tool with an adjustable chuck and electrical motor drive (adjustable as to speed) is indispensible in many operations.

In the branch of work known as coppersmithing, it is necessary to

become thoroughly acquainted with the special kinds of hammers and dolly bars, stakes, and blocks used in this work. Bumping and pounding on soft delicate metals are done with rawhide or rubber bumping hammers. For shaping the various pieces of the bumped metal, various types of metal stakes or dolly heads are used. Stakes are available in many forms and sizes. Oval head, ball head stakes, round head, square head, offset stakes, cone head, and coppersmith's stakes are used in various metal bumping. These may have the straight shank or offset shank, or be held in a vise, etc., depending on the nature of the work.

The other auxiliary machines for light work are found in every shop where they do sheet metal work. Angle and rod cutters, bench shears, slitting shears, angle notchers, and angle shears are all a familiar sight. The portable drill and the electric shear are indispensable for rapid production.

The various forms of light gauge punching tools, hand snips and trimming snips all form part of the tools the metal worker requires. Bending machines for rods, tubes, or rectangular bars also aid in rapid production.

For laying out work on flat sheets with irregular curves,one should become familiar with the beam trammel as well as its various uses. For marking lines accurately on long dimensions the surface gauge is indispensable to the accurate worker. The micrometer is used to a great extent to determine precise external dimensions of gauges of sheet stock. See Figure 24.

For testing specimens of sheet stock the Schleroscope or the Brinnel tester is found in stock rooms. One type uses the diamond hammer dropped on a specimen to be tested, and the reading recorded mechanically or optically. The other uses a hardened steel ball pressed into the specimen by high pressures, and recorded in the same way.

As in all assembly work, clamps play a very important role in construction. "C" clamps of various sizes, or the long shank ratchet clamp or machinist's clamps, all find their uses in the metal plane factory. Portable tools, such as grinders, drills, wrenches, caulkers, and screwdrivers may be pneumatically driven or electrically driven. To supplement all this, there is the usual array of auxiliary tools found in any production factory shop.

MICROMETERS

The micrometer is used to accurately measure the gauge and the thickness of light metal sheeting. For accurate determination of the thickness a micrometer is indispensable. The micrometer shown in Figure 24 is used for measuring the gauges of thin sheets and, hence,has a deep throat so that the distance toward the center of the sheet may be easily measured.

The spindle "C" is attached to the thimble "E" on the inside at the point "H". The part of the spindle which is concealed within the sleeve and the thimble is threaded to fit a nut in frame "A".

The frame being held stationary, the thimble "E" is revolved by the thumb and finger; and the spindle "C", being attached to the thimble,revolves with it and moves through the nut in the frame,approaching or receding from the anvil "B".

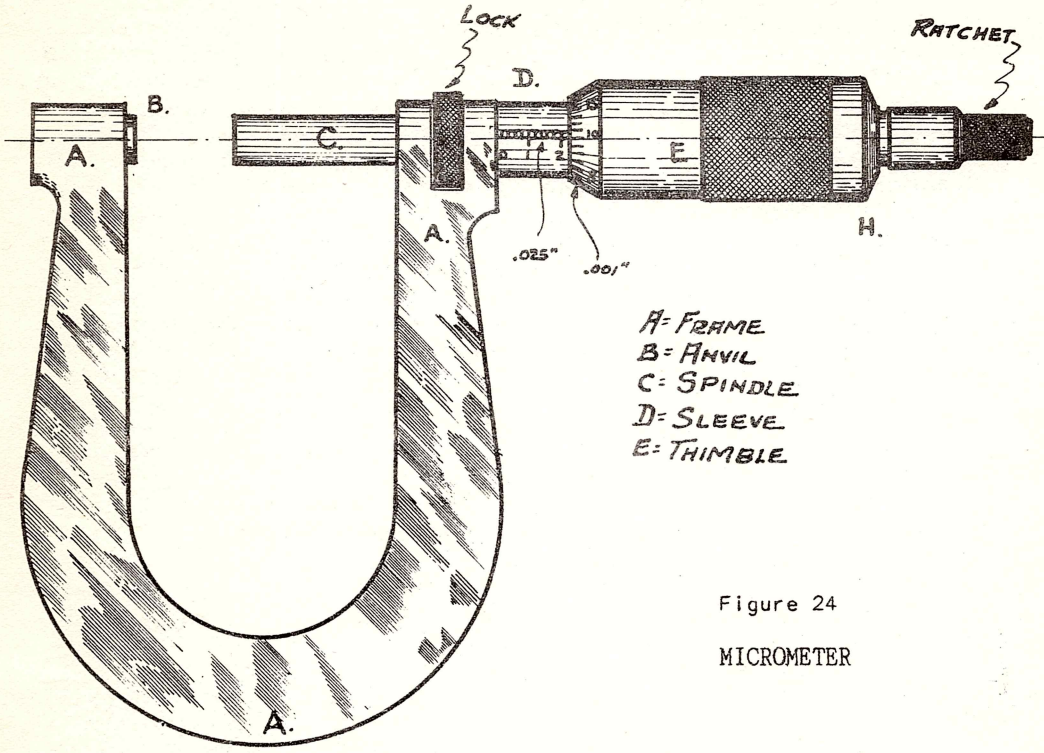


Figure 24

MICROMETER

The measurement of the opening between the anvil and the spindle is shown by the lines and figures on the sleeve "D" and the thimble "E".

The pitch of the screw threads on the concealed part of the spindle is 40 to an inch. One complete revolution of the spindle, therefore, moves it longitudinally one fortieth or twenty five thousandths of an inch. The sleeve "D" is marked with 40 lines to the inch, corresponding to the number of threads on the spindle.

The beveled edge of the thimble is marked in 25 divisions, and every fifth line is marked 0 to 25.

To read the micrometer, multiply the number of vertical divisions visible on the sleeve "D" by 25, and add to this the number of the divisions on the bevel of the thimble from the 0 line, which coincides with the horizontal line on the sleeve. For example, as the tool is represented in the illustration, there are 11 divisions visible on the sleeve. Multiply this by 25, and add the number of divisions shown on the bevel of the thimble "E" which is 10. The micrometer is then open (11 x 25 or 275, plus 10 or .285) 285 thousandths of an inch.

In the illustration the jaws are shown opened an exaggerated distance. The locking device enables a measurement to be kept for further reference. The ratchet control enables a fine adjustment of the sleeve "E". It is turned until it slips over the ratchet and then the reading is made, thus enabling a fine accurate measurement.

INSIDE RIVETING

Inside riveting is a process developed by the Junkers Works in Germany during the war. The process is particularly adapted to the Junkers type of wing spar. It is included here for its interesting features.

Inside riveting of the outer skin to the tubular members of the internal structure is accomplished by the use of special forms of dolly bars and other equipment. The rivet originally used was of soft iron. Dural rivets are now used exclusively. The Junkers organization developed several interesting tools to accomplish this work.

An ordinary rivet holder for sheet work or tubular member work is shown in Figure 25. The rivet holder is simply a tool, the shank being whatever length is desired. This holder is inserted inside the tube, the rivet headed over from the outside by pneumatic tools, and bucked up by a special dolly bar.

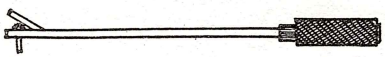
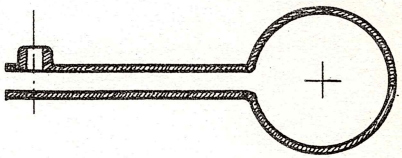


Figure 25

RIVET INSERTER



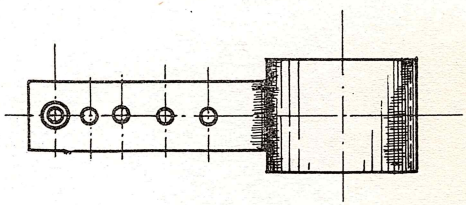


Figure 26

RIVET EDGE DISTANCE GAUGE

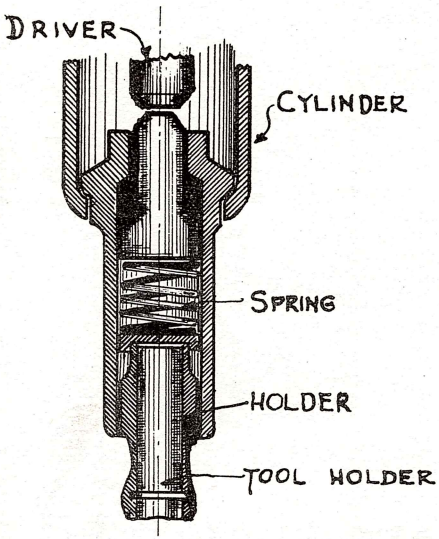


Figure 27

PNEUMATIC HAMMER TOOL

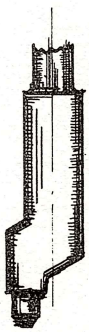


Figure 28

OFFSET RIVETING DIE

A Junkers wing is covered from the tip into the root. It is covered this way because of the tubular structure. The rivets are inserted by the rivet inserting tool. Then the rivet is bucked up by an inside riveting dolly bar. The designs of several are shown in Figures 29 to 32, inclusive.

For riveting the sheet and spacing the holes from the edge, an adjustable gauge shown in Figure 26 is used. The edge distance is adjusted by a tapered peg inserted in the holes. The driving tool for riveting is the ordinary pneumatic hammer, the head of which is shown in detail in Figure 27. The use of offset dies for heading over rivet shanks

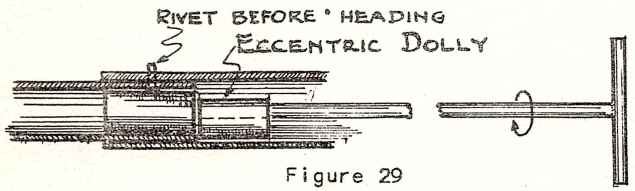


Figure 29

OFFSET DOLLY BAR

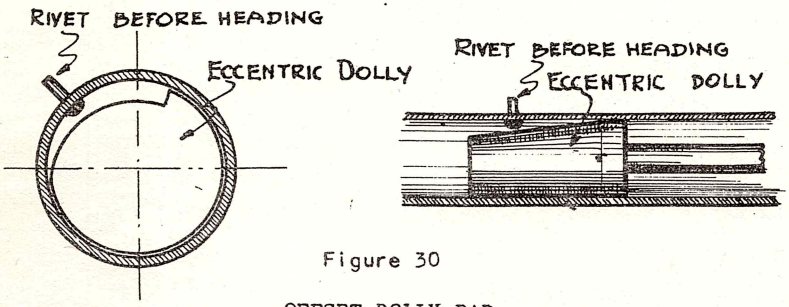


Figure 30

OFFSET DOLLY BAR

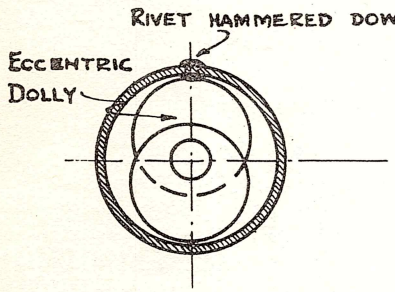


Figure 31

OFFSET DOLLY BAR

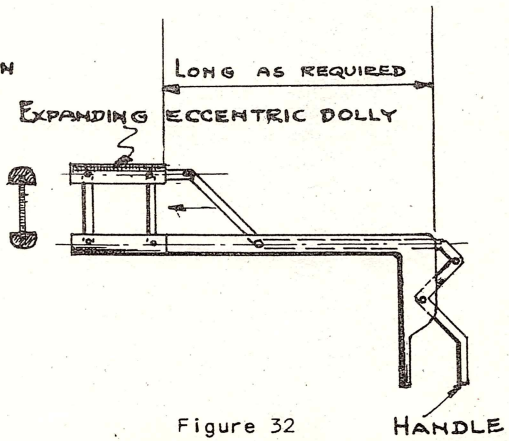


Figure 32

INSIDE RIVETING DOLLY BAR

for flat sheet riveting is extensive where it can be done in a machine. See Figure 28. The offset die allows clearance for flanges and edges, such as in aileron edges at the hinge line or elevators.

The dolly bar types for inside riveting are many with the length of the shanks running to long dimensions. An offset dolly bar for inside riveting is illustrated in Figure 29. This dolly is inserted where the tubes are telescoped inside each other. The rivet is inserted and the dolly bar then is inserted inside the tube and forced inside, so that it fills the tube, forcing the rivet head up tight against the tube wall. The long dolly bar shank is turned by a twisting handle at the end. The rivet is headed over by a pneumatic hammer.

Another form of offset dolly bar is shown in Figure 30. This type is the most common form for small diameter tubes, such as is used in a small wing structure. The cross section illustrates the method of usage in Figure 30, and also the tapered shank. The tapered shank has a cam action on the rivet head, and forces it tight against the tube wall. The rivet is then headed over pneumatically.

Another form of offset dolly bar is shown in Figure 31. This is merely two hardened steel cylinders keyed to a long shaft and inserted against the walls of the tube. The two cylinders are nearly tangent to the inside walls of the tube. Enough space is left to tightly seize the rivet head and hold the same while it is being headed over.

For large diameter tubes the Junkers works have developed a special long shank expanding dolly bar. This type of dolly is used for tubes of several inches diameter in large wings. The expanding type is shown in Figure 32.

For riveting special control surfaces, a press type of machine is also utilized. This is nothing more than the ordinary treadle operated machine with a heading die working up and down like a die press and driven by a flywheel and motor.

A pedestal type of inside riveting dolly is also in use. This machine operates on the principle of an expanding internal dolly bar controlled by the operator from a foot treadle, and rivets are headed over by means of a pneumatic hammer. There are many types of expanding internal dolly bars. They are more or less modifications of the original type.

Contrary to what may be expected, very few defective rivets have been found in Junkers' structures of the wing when internally riveted. Great pains are taken to insure this. The rivets are all plumbed up accurate so the shank is vertical to the tube walls. Elaborate inspection tools have been developed, using a periscope arrangement and illuminating the interior walls of the tube. These devices magnify the driving of the rivet and a defect is remedied at once.

Contrary to general expectations inside riveting, when developed on the scale that the Junkers Works at Dessau, Germany, have arrived at, is no more costly than the ordinary type;and with specially developed tools it is quickly accomplished. It has proven to be durable and trustworthy in hard service.

METAL STRIP FORMING

In Europe, especially in England,the widespread use of high tensile

PNEUMATIC-HAMMER SIZES FOR COLD DRIVING OF RIVETS

RIVET SIZE	SIZE OF GUN	BLOWS PER MINUTE.
1/8-3/16"	1-1/16 x 2	2980
3/16-5/16"	1-1/16 x 4	1524
5/16-3/8"	1-1/16 x 6	1055
3/8-1/2"	1-1/16 x 8	948

sheet steel or strip in aircraft construction is a serious competitor for lightness to the shell structures of all-metal in the U.S.A. Strip steel is of very light gauge and is usually of the stainless variety. The metal is worked into various structural shapes by the judicious use of metal rolling dies and the drawbench.

The material is fed into a forming machine similar to a rolling machine in the steel mills. See Figure 33. The forming is accomplished progressively by a series of roller die operations on a long drawbench. The metalis fed into the machine and drawn through the series of rollers. Each operation is conducted at an increasing angle of forming until the desired shape is achieved. The material is rolled into many of the standard structural sections common to airplane requirements. These shapes are then worked into the airplane structure, being riveted in place with tiny rivets.

Strip construction is unknown at present in the U.S.A. The reason is the lack of high grade tensile steel alloys. The technique of the rolling die is not widely known either. Strip steel is ideal as a material for airplane structures. The strength is very high to its weight. Light gauges may be used. This means easy workability and reduction in precise heat treating, and other operations common to aluminum construction. The material has a very high fatigue strength under high strains. Being rustless and stainless, recommends it well for serviceability and maintenance.

This form of construction is not as costly in production as what may be first opinioned. With modern methods the final cost is actually less than an all metal shell structure. Semi-skilled labor may be used in the operations of assembly. In service, the feature of being fabric covered facilitates rapid inspection for fatigue, if any, or deterioration.

The strip method of construction is adapted to rolling in any form. Wing spars utilizing this method are very light in weight and strong when braced accordingly. The material has passed the required specifications of the R.A.F. Steel is perfect as an aircraft material. With suitable design the light gauges can be made into a strong structure. It is adapted to rapid production. It punches and forms easily. Roller die forming is less expensive than drop brake forming. The attractiveness of this form of construction, while being old in development, should bear watching. It has much to offer.

Dural spars have also been produced by this method of rolling. See Figure 34. The use of them in aircraft structures has proven satisfactory abroad in a number of designs. At present the use in the U.S.A. is practically nil. Dural rolling is subject to the limitations of the material as in other forming operations.

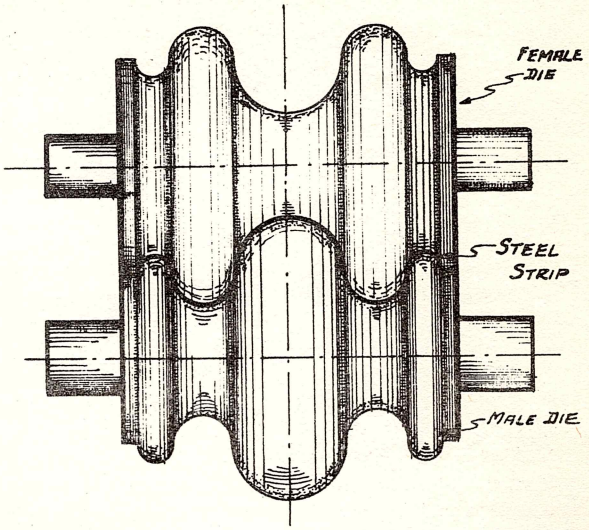


Figure 33

ROLLER FORMING DIE ON STRIP MATERIAL

The above illustration shows the method of rolling strip material. The dies intermesh. The sheet is gradually formed to the contour desired. Lubrication of strip is desirable.

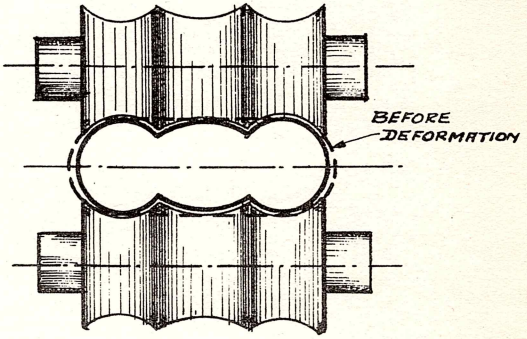


Figure 34

METHOD OF FORMING SECTIONS TO SPECIAL SHAPES

This illustrates a standard tubular section of large size with rounded ends being deformed for strength for use as a spar. The dotted lines show the original shape. The rolling is done in a series of progressive rolls to the desired shape.

CHAPTER IV

BUILT—UP SECTIONS AND STRUCTURAL SHAPES

Metal aircraft construction has necessitated the use of a great number of structural shapes ordinarily not employed in structures of any other kind in the mechanical engineering field. Box girders, I beams, H beams, bulbular angles, etc., comprise in their various forms the commonly utilized basic elemental shapes in structural work.

On the other hand, the exigencies of great strength to minimum weight has resulted in creating research into the possibilities of other shapes structurally than those used in ordinary engineering of structures. For this reason the multiplicity of shapes utilized in the fabrication of metal aircraft is numerous although each is more or less a modification of some basic elemental shape.

Since the production of aircraft is highly competitive the aspect of production cost must be taken into consideration. For instance, is it cheaper to use an "I" beam of extruded dural section than one of built-up section? Is it cheaper to use a box metal spar or one of the modifications of channel and I beam? Then when that is settled, comes the other question of weight and which is the most economical of weight in relation to strength and cost. Cost and weight go hand in hand along with the weight to strength ratio, because the light dural alloys cost roughly three times as much as steel of high qualities.

ROLLED SECTIONS FROM DIES

The use of standard rolled die sections, carried in large quantities by the manufacturing company of alloys of dural material, is not as widely utilized as might be supposed. Certain numbers of the smaller shapes are used, such as tubes, angles, channels, etc., but the majority of the larger structural members are "built-up" sections.

The I beam while ideal for many reasons, particularly of cost relation to weight and strength, on the other hand is deep in section, requiring considerable auxiliary members to brace the same against torsion in the wing truss. Therefore the cost of the original item is increased by additional labor and material.

On the other hand the rolled section is invariably the easier to install in a structure since it is available in long lengths, and can be readily and quickly worked into the structure. The use of the rolled section, however, is limited by the fact that various wing structures are nearly always in variation to the stock sizes of the rolled bars, with the result that I beams are nearly always built up of a rolled bulbular angle, and the shear plate fabricated from sheet stock and stiffened.

Rolling of dural sections is accomplished much the same as steel billets are rolled into shape. The alloy is produced in large bar billets and forced by pressure under a large rolling die held in a massive frame while the dural is heated to intense heat. By rolling backward and

forward the shape is finally produced, and then set aside to cool in a straightened form.

Rolled sections have not had a very wide application to aircraft, mainly, because a rolled section is always heavier for a given linear dimension by reason of the large amount of material at the corners of the various parts of the members. Since weight is important, this amounts to considerable on a long run of spar or longeron length. For this reason, and the scarcity of the stock shapes to fit ordinary aircraft production, the rolled shape has not been as widely used as may be possible with increased production.

EXTRUSIONS

The majority of shapes are produced by the process of extrusion. This is merely a manufacturing process whereby the shapes not possible of forming by rolling may be made, and in continuous lengths. It is possible to extrude shapes in any of the compositions ranging from the SO alloys to the ST alloy, some of which are difficult to roll.

The tools used in extrusion are much less expensive than the heavier rolling dies, and thus it is feasible to supply special shapes at a lower cost than rolling. The material and the machines limit the width to less than six inches and not less than 1/16 inch in thickness. Extrusion tools are merely a form of hydraulic presses, the pressure of which depends on the elastic limit and the yield point of the material.

BUILT-UP SHAPES

The built-up or formed shape utilized in aircraft fabrication is the most widely used method at the present time. Built-up shapes, however, while satisfying the condition of construction, impose labor cost in assembling and fitting together the various parts of the member.

Built-up shapes are more or less always a modification of a rolled shape. The purpose for a shape of this construction is to secure some specific advantage from either weight, size, strength, or cost. On examination of a built-up shape the basic form of the element will generally be some form of the box, the "I" beam, the "H" beam, or, if otherwise, a combination of the several forms.

In figuring the strength and bending of a built-up shape the first thing is to determine what modification of the basic elementary section it represents, and from that point some sort of accurate determination may be made of the resistance to bending and torsion.

The built-up shape is always made in several parts, if of heavy gauge, and riveted together. The riveting is performed in the usual method, the same as in other forms of construction of aircraft parts. A built-up shape, in general, may be resolved into a top and bottom heavy flange member and light web members with stiffeners. This is more or less the principal of any beam.

Aside from riveting, the only other method of joining the various parts up together, without resort to welding, is to seam and hem the material together. This, of course, is not adaptable to the dural light gauge members, since sharp bends and radii are to be guarded against,but

it is quite all right when using high tensile formed plates, such as are used in England.

The wide use of welding in other parts of the aircraft structure has made it possible to build up fairly light weight spars using this method of joining. Welding, while less costly than riveting, does have the disadvantage of slightly lowering the strength qualities of a tubular flange member when welded in numerous places with small intervals between; such as in a system of Warren truss diagonals when used for the rib.

Shot welding is being used more extensively. Fleetwings have produced good spar and other aircraft parts, such as ribs and braces, using the shot welding method of joining component parts together. The shot welding is done electrically. The Edward G. Budd Company has perfected the use of shot welding and has produced a complete airplane using light gauge high tensile steel shot welded together. In light of the coming developments and previous experience much can be expected to lower the cost of built-up shapes by shot welding over the process of riveting.

While being light in weight built-up sections possess the property of being made stronger by clever use in determining the grain direction of the various sheet alloy stock. While this seems insignificant it does lend appreciably increased strength, since the direction of the grain can be so utilized in sharp bending that the maximum of strength may be secured.

CHAPTER V

METHODS OF FABRICATION

METAL SHELL FUSELAGES

Metal fuselages of the shell or monocoque type are rapidly gaining favor in current airplane design. The advantages of the shell type of structure are many for aerodynamic and structural reasons. The shell type of structure of cylindrical form or modifications thereof is the strongest for the least weight, and offers minimum drag for a given head on area displacement.

The cost of producing the shell type of structure is mainly one of familiarity of metal part production. Aside from the greater cost of the alloys used over that of the ordinary welded steel fuselages, the extra cost of riveting is rapidly being decreased by better production methods and the perfection of better riveting machines. Then after all, the exigencies of the era of transposition from steel tubing frameworks, fabric covered, to the all metal, is merely one of adapting methods peculiar to the requirements of all metal aircraft fabrication and applying modern production methods.

There are many forms of fabrication of metal structures. The metal frame structures (shell type, welded tubing type of steel, the frame or strip type of various alloys) each have their own particular merits. However by ingenious use of the lighter alloys, all-metal aircraft of transport plane size are carrying at speeds of 200 miles per hour nearly 95% of their gross weight in pounds, and this speaks for the efficiency of the multicellular and the all-metal structure when ingeniously engineered.

FULL MONOCOQUE TYPES

There are extremely few examples of the full monocoque form of fuselage, and by that we mean a fuselage of which the outside skin is capable of maintaining the shape and carrying the longitudinal stresses with merely bulkheads of the round or elliptical variety as the auxiliary bracing members for strength.

The most prominent examples of recent date are the Vultee V-1-A which uses a skin braced by a ring bulkhead of channel section closely spaced at intervals of a few inches. The sheets are not performed in this design. They are merely flat pattern strips riveted to the bulkheads overlapping each other. The longitudinal contours are so gradual that performing is unnecessary. This form of construction is easy to manufacture and very high in strength to weight ratio. The skin is riveted throughout. A cross section detail illustrates the construction in Figure 35.

Shown in Figure 36 is the construction of the YB type of Martin Bomber fuselage cross section. The construction is somewhat unusual in as much as the skin is applied smooth with the top and the bottom of the smooth skin stiffened longitudinally against buckling by a reinforcing

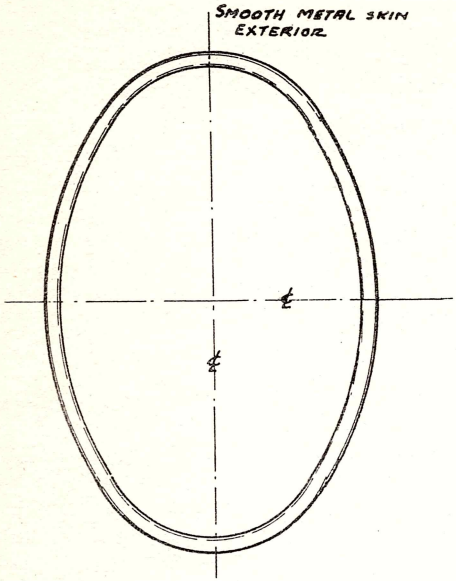


Figure 35

VULTEE

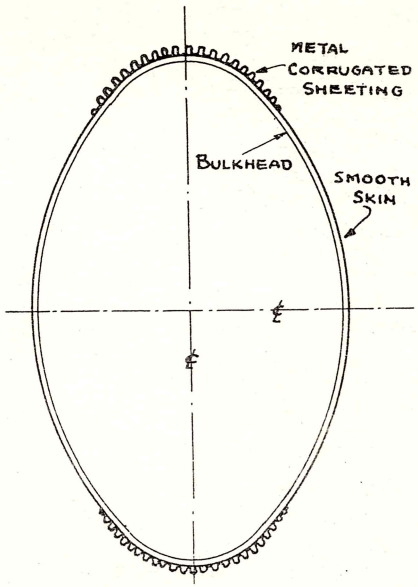


Figure 36

MARTIN "YB" FUSELAGE

sheet of corrugated dural of about 3/4" corrugations laid on in long sheets and formed to the curvature of the fuselage.

This form of construction is very efficient with a low weight to strength ratio. The success is attested by the great carrying capacity of the bomber, and its wide acceptance by the U.S. Air Corps. The smooth skin is preformed and applied over a series of bulkheads, whose structural elements and shapes vary throughout the length of the fuselage. The structure is riveted throughout, and the sides are smooth skinned the entire length. The application of the longitudinal corrugations increases the strength enormously.

The Bernard metal type of fuselage is widely used in France. This is a metal shell structure with the skin taking the loads longitudinally and strengthened by bulkheads all riveted together. As detailed, the engine bearers are carried on heavy gauge members riveted to the skin. The arrangement is indicated in Figure 37.

The theoretical monocoque type is illustrated in Figure 38, shown with a ring bulkhead with lightening holes. The lightening holes do not detract structurally from the strength of the shell and do save weight. The skin in this case would be either in small sheet sizes unformed or large sheet sizes preformed, or the strip sheet method as exemplified by the Vultee form of construction.

The bulkheads under the exigencies of low cost are generally manufactured in several segments and jointed together by riveted splice plates. This does not seriously detract from the efficiency of the structure. A bulkhead of channel shape is very difficult to form or to

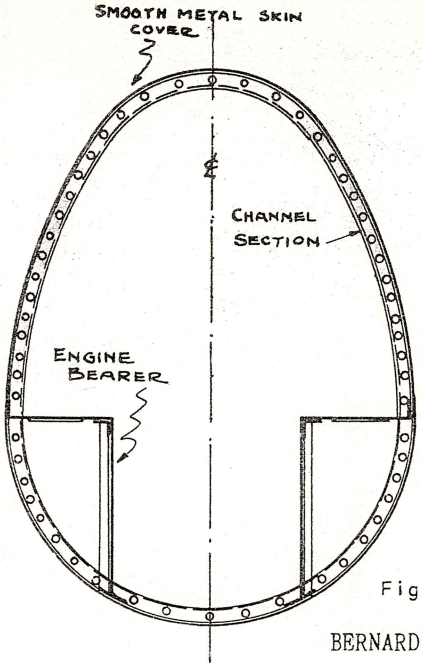


Figure 37

BERNARD RACING TYPE

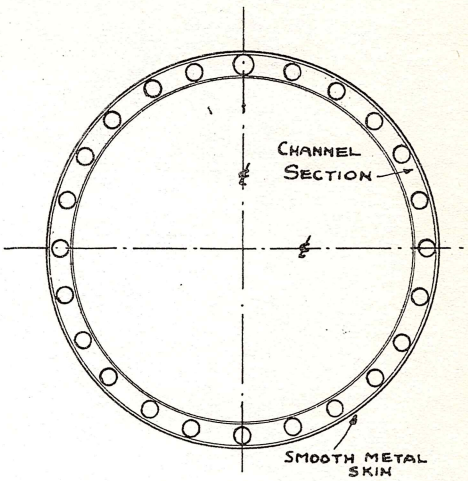


Figure 38

MONOCOQUE TYPE

roll due to stretching and compressing the metal in each side and the requirements of elaborate forming equipment. Therefore the use of the monocoque fuselage depends in metal on several factors beside the aerodynamic aspect, which are cost, primarily, and ease of production.

In Figure 39 the Thaden type of fuselage is shown. This form is extremely light and makes use of several features not ordinarily incorporated in American monocoque practice. The bulkhead is a tubular member formed as shown and inside riveted. To obviate the numerous difficulties of inside riveting, the frame is lightened by holes opposite each rivet whereby the buckerup dolly tool may be inserted as the rivet is headed over. The longitudinal strength of the fuselage is carried by the outer corrugated dural shell plating in long sections. For great strength the longer and the larger the shell plating the greater the resistance to bending and torsion.

The Budd Company in America has extensively developed the use of shot welding for aircraft use. The experimental patented arrangement shown in Figure 40 makes use of ring bulkhead of obvious shapes with shell plating in long longitudinal strips shot welded to the inner ring formers. This type of construction in high tensile steel or dural alloys is very light in weight.

SEMI-MONOCOQUE FUSELAGES

This form of construction is the most popular and widely used in the contemporary designs of metal shell fuselages. This method combines the advantages of the other with high strength although somewhat heavier.

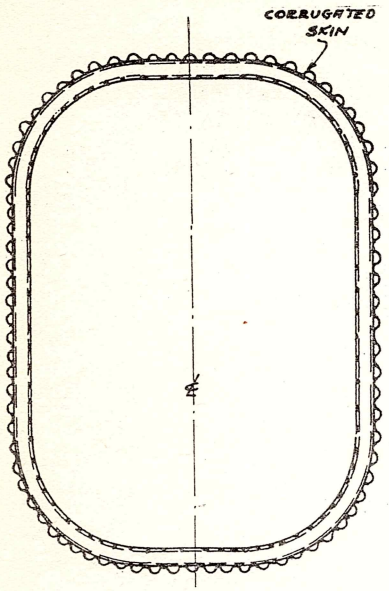


Figure 39

THADEN

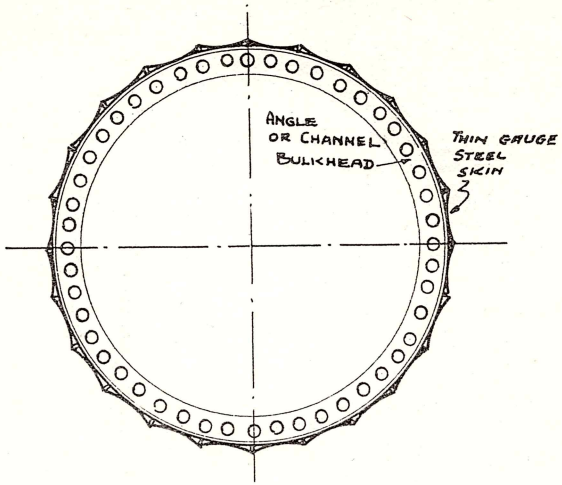


Figure 40

EXPERIMENTAL SHOT WELDED
BUDD PATENTED

It has the advantage of greater multiplicity of structural members for anchoring the internal equipment, and also for stiffening the shell structure against denting and other deformations.

The design of the semi-monocoque fuselage may be divided into two classes. One class uses a longitudinal system of frame members, while the other utilizes a system of internal trussing under the floor with a system of stringers, bulkhead and outer skin to carry the loads. Both types have their obvious advantages. The Clark and the Douglas are examples of the latter, while the Boeing is an example of the first mentioned.

METAL SHELL STRUCTURES

The efficiency of the Northrop Aircraft is widely recognized. This type of construction makes use of a special fuselage design perfected by the Northrop organization, and by which enormous strength with light weight is achieved. The fuselage is a combination of stringers and bulkheads. but not in the ordinary sense of the word. See Figure 41.

The stringers are part of the shell plating with a special formed "J" section being formed from each piece of skin plating. The skin is applied in narrow sheets of short or moderate length. Each plate overlaps the other, the "J" part forming the longeron stiffener for the outer shell; and the plate is riveted to the ring bulkhead, which is like-

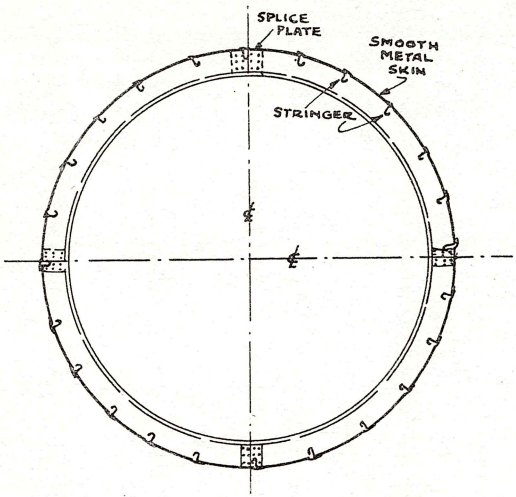


Figure 41

NORTHROP TYPE

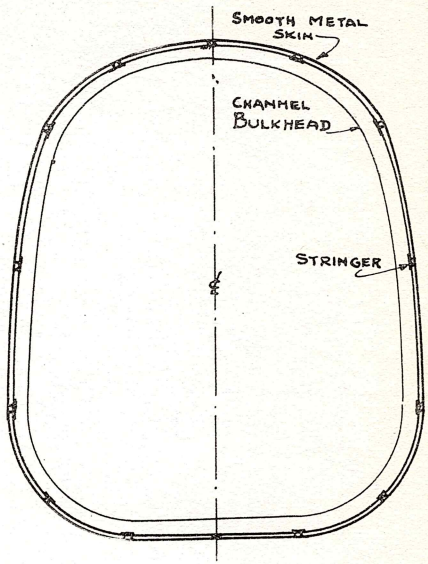


Figure 42

BOEING TYPE

wise built of a "J" section preformed to the desired roundness. The whole is riveted together.

This type of fuselage eliminates considerable weight that is generally present in the orthodox monocoque type without any sacrifice of strength. The shell carries all loads in any case with the parts of "J" form passing through the bulkhead formers where necessary for the longer sheets when applied on the fuselage. This makes for great strength. It also eliminates the need for riveting the stringer sections as well.

The Boeing 247 transport plane utilizes the fuselage construction shown in Figure 42. This construction is composed of bulkheads (both heavy with lighter ones intermediate) and stringers, all of a channel section. The fuselage framework is lightened by holes and the skin is riveted to the framework directly. This form of fuselage is very stiff and rigid. The curved sheets are preformed, but where the radius is large, flat sheets are applied and sprung into place.

The experimental 4 piece bulkhead is shown mainly for a comparison. This type of bulkhead is cheap to produce in quantity, and the edges are both flanged for stiffness. The bulkhead in actual installation would be strengthened by a system of stringers. See Figure 43.

The Clark GA-43 type of bulkhead is a shell with a channel former to preserve the shape and extruded "J" sections for the longitudinal loads and skin stiffening. The floor acts as a metal box section and is corrugated, with a system of bracing carrying the heavy fuselage loads and which extends the length of the cabin. This bulkhead is very strong. See Figure 44.

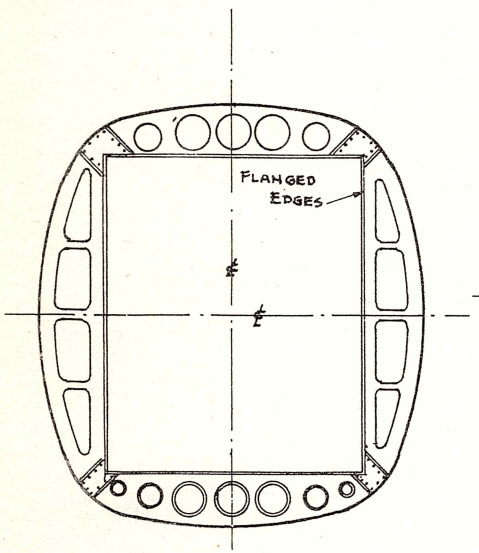


Figure 43

EXPERIMENTAL 4 PIECE
MAIN BULKHEAD

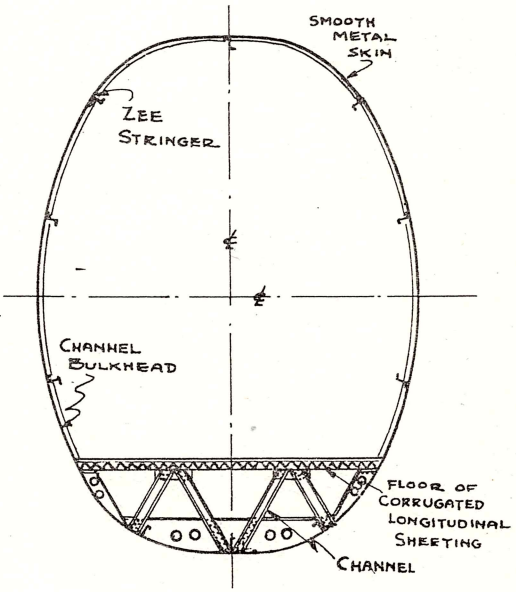


Figure 44

CLARK GA-43

An experimental form of monocoque fuselage is shown in Figure 45 with the use of ring bulkheads of desired shape and special extruded longitudinal members of "J" section, all riveted together.

The Detroit Aircraft form of fuselage is shown in Figure 46 with a system using preformed sheets and four longitudinal "T" members of extruded section to carry the fuselage loads. This type of construction proved adaptable to modern design as a transition from wooden fuselage of the same type.

The semi-monocoque design shown in Figure 47 is merely a system of ring bulkheads anchored to a system of longitudinal channel members of light gauge but of large dimension. This form is merely experimental and shown for comparison. The ring bulkhead is angle or channel form, as required, and made in several pieces which are then riveted together with splice plates.

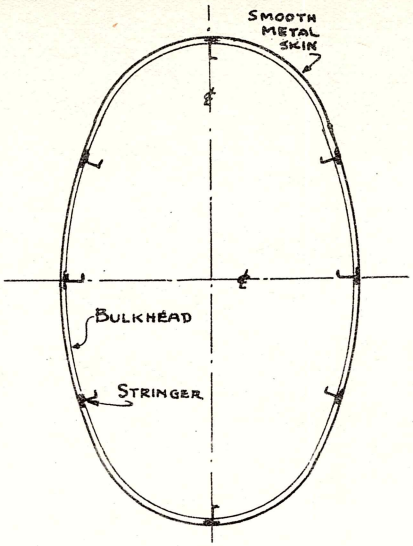


Figure 45

EXPERIMENTAL SEMI-MONOCOQUE

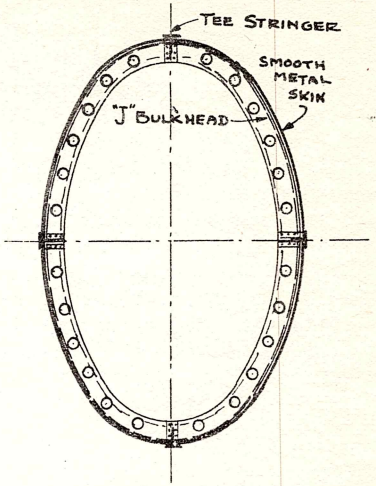


Figure 46

DETROIT AIRCRAFT

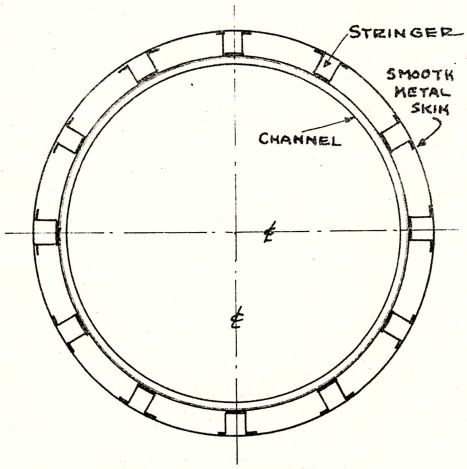


Figure 47

SEMI-MONOCOQUE

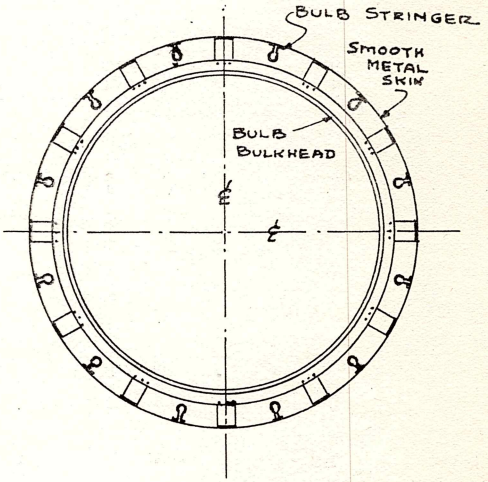


Figure 48

GENERAL AIRCRAFT

The fuselage section shown in Figure 48 is a type developed by the General Aircraft Co. of Buffalo. The fuselage has an outer metal shell with the angle plates riveted thereto, being specially formed bulbular sheet stock section rolled to the desired form. This type of shell construction is further stiffened by longitudinal stringers riveted to the outer shell of the same bulbular section.

The Vickers-Wibault, shown in Figure 49, is an example of a composite, semi-monocoque with frame members to carry the fuselage stresses. This form of construction is all built of alloy dural and is very strong though somewhat heavier than the lighter types. The four segments of the bulkhead are riveted together with splice plates, and the edges of both inner and outer members are all flanged and corrugated. The shape is further maintained by diagonal bracing members, for each half of the fuselage, and stiffened by the skin and internal bracing members.

The Curtiss Company has developed the patented construction shown in Figure 50, this form being very efficient. The longitudinal members are merely tee sections braced with angles of smaller dimension -- all running longitudinally. Four extruded "J" members are alternated at the axis points of the elliptical shape. The fuselage uses a preformed sheet all riveted to the stringer members, depending on the forming for keeping the required shape. This type is very light in weight and extremely strong.

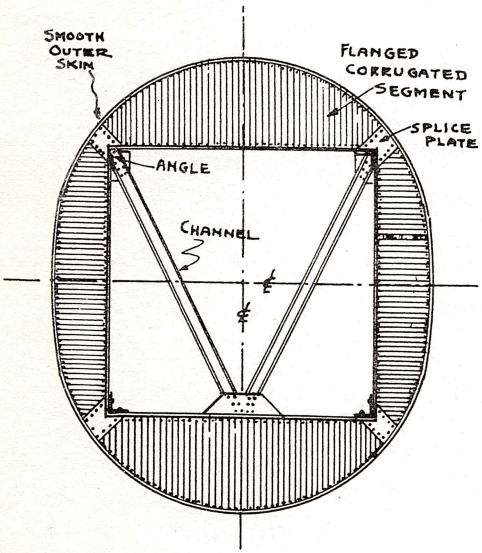
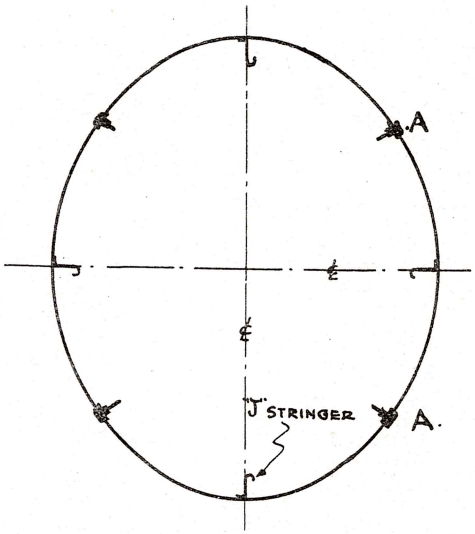
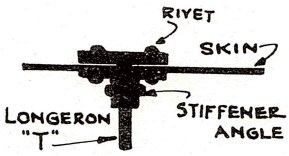


Figure 49

VICKERS-WIBAULT





DETAIL "A"

Figure 50

CURTISS
(Patented)

METAL SHELL FUSELAGES

The Dewoitine bulkhead shown in Figure 51 is an example of late French construction. The bulkhead is made in several pieces with splice plates riveted together with cut-outs for the long main longerons, and alternated skin stiffeners extending the length of the fuselage. All edges of the bulkhead are flanged.

In Figure 52 the Bleriot bulkhead used in the long range monoplane is shown mainly for comparison. This bulkhead is used with a composite wooden monocoque construction.

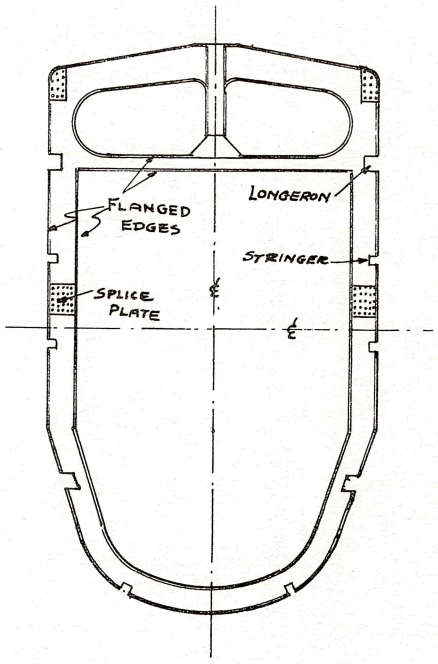


Figure 51

DEWOITINE

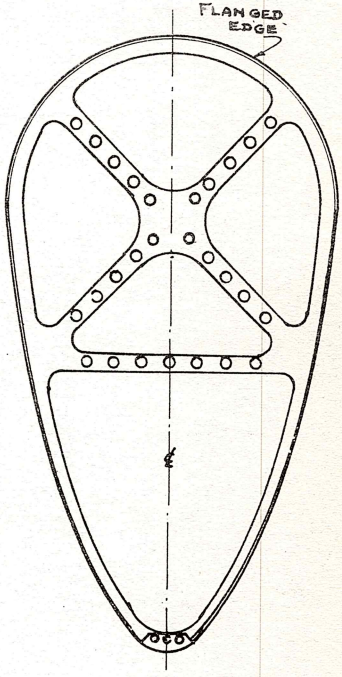


Figure 52

BLERIOT

The construction shown in Figure 53 is an example of both skin structure and longitudinal stiffeners formed in the skin itself. It has the disadvantage of flat sides, but the structure itself is very strong as it is braced by corner longitudinal stiffening members. The skin is applied in long strip preformed sheets of dural alloy.

The best example in large plane construction is undoubtedly the Douglas. The bulkhead construction is typical of the excellence of design of the component parts. Figure 54 is self explanatory. This form of bulkhead is very light for its size and dimensions, and is produced easily in production as it is made of several parts riveted together. The lower portion is a half elliptical box type of section with the corrugated flooring aiding in carrying the longitudinal cabin loads. This form of construction has great strength torsionally and longitudinally. The bulkhead is adaptable to quick production, which is a great advantage for low cost. The longitudinal stringer members are extruded dural alloy angles riveted to the clips at specific intervals on the bulkhead. The skin is applied to the outer flange of the bulkhead with the joints alternated.

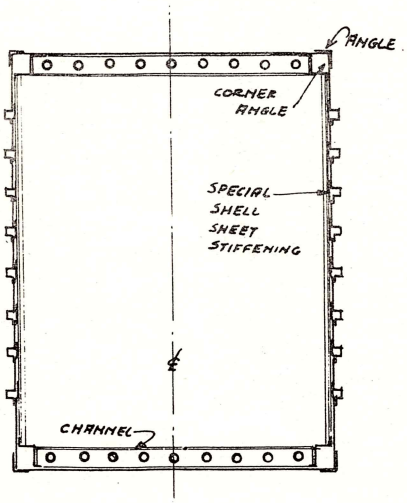


Figure 53

METAL AIRPLANE CO.

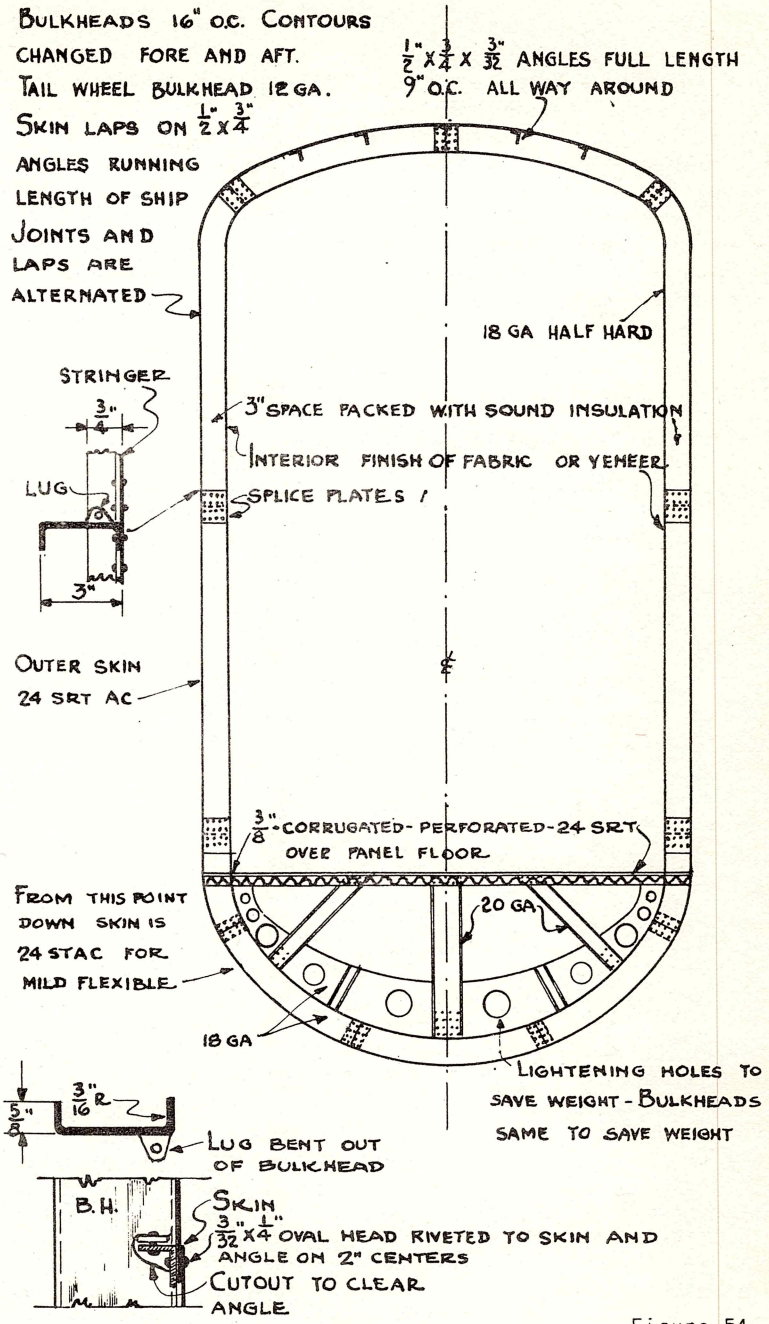


Figure 54

DOUGLAS DC-2 BULKHEAD

The Cadet Series

METAL BULKHEAD PARTS

In Figure 55 the construction of a typical water-tight bulkhead, as used in the Martin Clipper seaplane, is shown. The bulkhead is a flat sheet of dural alloy with stiffening angles and members at specific intervals. The skin covering is smooth with the usual corrugations running along the top and the bottom of the hull for additional stiffness.

The side shell plating is smooth and further reinforced by lateral stiffeners intersecting the vertical stiffeners for additional side wall strength and to eliminate buckling of the bulkhead side walls from rough water loadings.

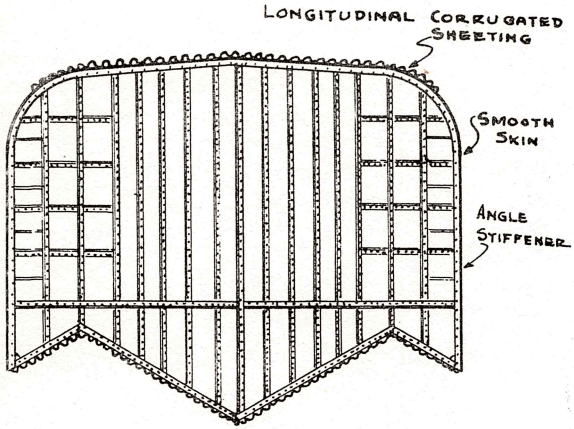


Figure 55

MARTIN CLIPPER BULKHEAD

As an example: In Figure 56 the means for attaching a landing gear member fitting to the side wall of the monocoque structure is shown. To distribute the loads which are rather highly concentrated by reason of the small bearing area of the fitting, additional laminations of light gauge stock are applied at this point; consequently building up a layer of heavy material at this point that absorbs the shock without damage to the thin metal shell. In applying any form of concentrated load the area and means to dissipate that load must be carefully studied and so applied that the unit load per square inch is correspondingly small. By means of this method the efficiency of thin shelled structures is increased greatly.

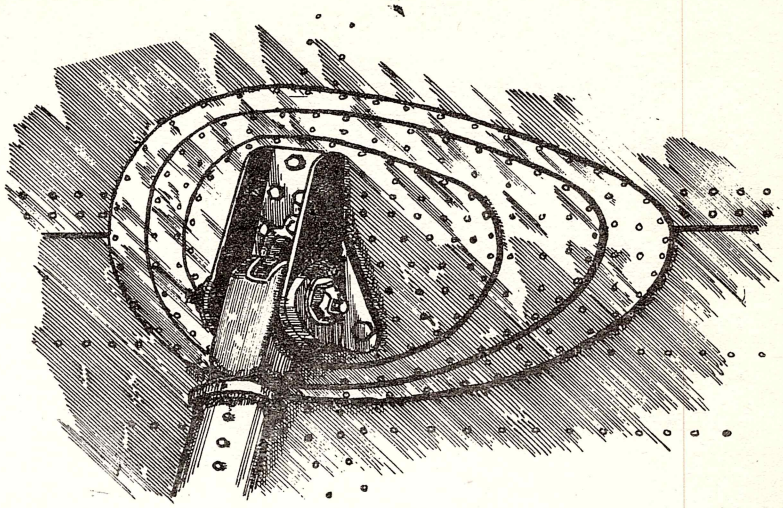


Figure 56

DETAIL OF LANDING GEAR MEMBER ATTACHMENT TO MONOCOQUE FUSELAGE

The mail plane shown in Figure 57 is a typical example of modern multicellular wing construction and semi-monocoque fuselage arrangement. The vertical lines shown indicate the vertical bulkhead positions and the spacing of the same.

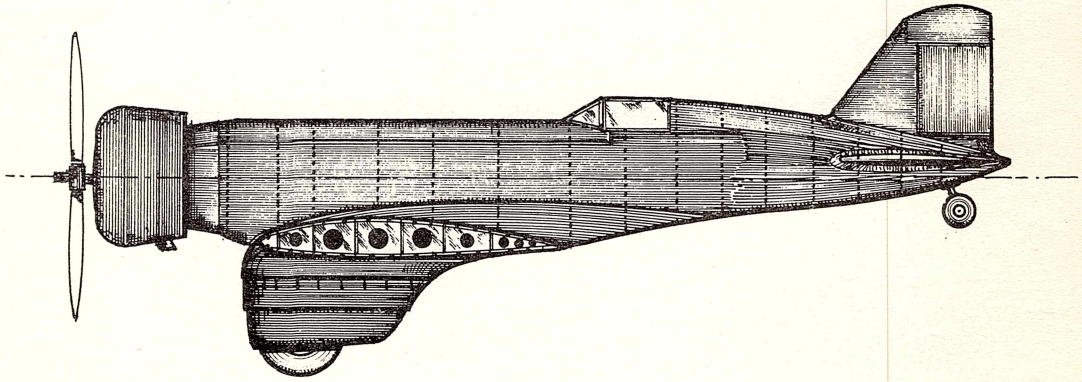


Figure 57

SCHEMATIC ARRANGEMENT OF TRANSVERSE FUSELAGE BULKHEADS IN A MAIL PLANE OF MONOCOQUE FUSELAGE CONSTRUCTION

Figure 58 gives the detail dimensions of the standard corrugations of dural sheeting available for aircraft use. The radius points are taken to the center of the sheet thickness where accuracy is necessary. For all practical work the dimensions given are close enough.

Corrugated sheets are manufactured from flat sheet stock and forced through a series of roller dies. The corrugations add greatly to the rigidity of the sheet since the metal is disposed equally on either side of the neutral axis, giving the sheet a modified form of a beam. Hence their use in stiffening of wings and long fuselage or spar members, and the covering of the same.

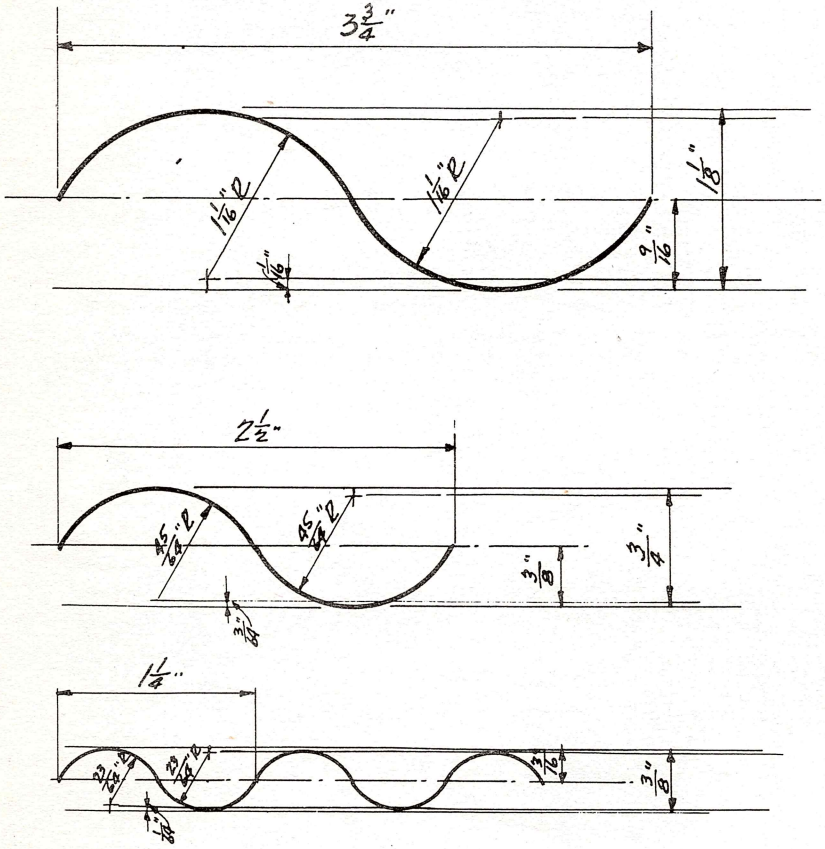


Figure 58

STANDARD CORRUGATIONS

METAL FRAME FUSELAGES

Despite the numerous advantages of an all metal shell structure the metal frame fabric covered structure is not obsolete in many ways. This form of structure in its various ramifications will find wide application in many new planes yet to be built and, therefore,a knowledge of some of the problems encountered in this form of construction is essential.

The Curtiss Company in the U.S.A. utilize a tubular riveted dural fuselage with flattened tubes at the end, riveted together with steel wrap fittings. This type of fuselage is used in the Hell Diver, Curtiss Falcon and Curtiss Thrush. A fuselage of this type weighs about 25% less than the ordinary welded steel fuselage although it is not quite as strong, and it is subject to corrosion if unprotected. See Figure 59 for the details of the joints.

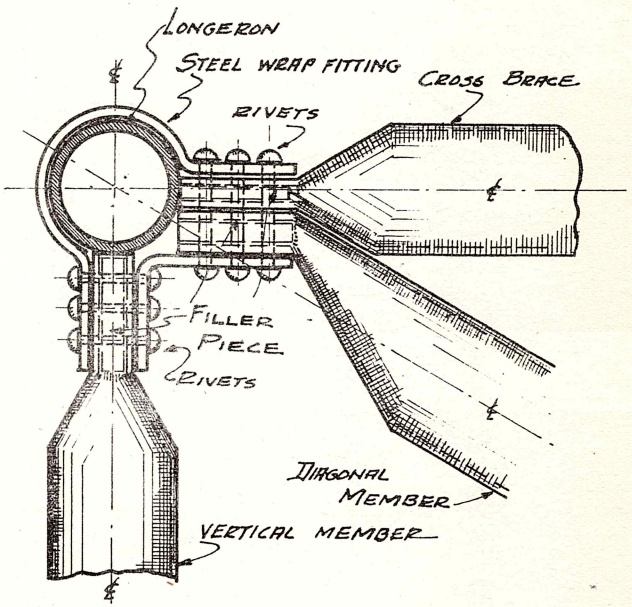


Figure 59

RIVETED DURAL FUSELAGES.

In the effort to produce lighter fuselages the use of dural tubes have been utilized in a structure employing a system of steel fittings riveted to the tubes to hold them together.This system has been developed by the Curtiss Company and used extensively. The ends of each tube member is flattened and filled with a dural filler piece to prevent too severe crushing effects on the ends of the tubes.The fittings are drilled and riveted all into a homogeneous structure. The inner fitting is an angle fitting,while the outer section fitting is a formed steel fitting, of the wrap type. The diagonal member in this form of joint is off the neutral center at the riveting portion of the joint. This produces a

small moment eccentric arm of the forces in the tube, not large enough, however, to seriously do any harm to strength. Joints of this type have been used in the Curtiss Hell Diver, the Thrush, the Falcon, and other aircraft.

RIVETED FUSELAGES

This type of construction uses a large angular wrap fitting of high strength steel, joining the diagonal, top, cross, and vertical diagonal members of the fuselage structure together. The inner fittings are two ninety degree angle pieces riveted to the side vertical, diagonal, and other members, and reinforces the joint. This type of construction is adaptable to either dural or steel tubing. The various members are held by means of long shank member rivets which pass through the fittings and the tubular members from side to side. Fuselages of this sort have met with a good degree of success under service conditions. The rivets in this case act also as long pin members.

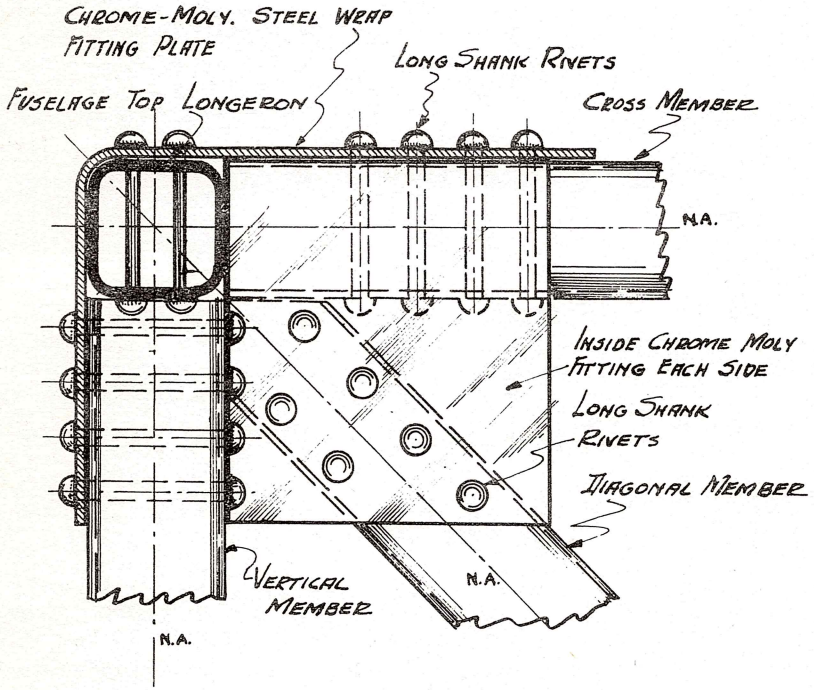


Figure 60

DETAIL OF A RIVETED FUSELAGE CLUSTER
OF TUBULAR LONGERON MEMBERS

The Vickers Wibault system in Europe consists of a "T" member, both for the longerons and vertical, horizontal and diagonal members,all riveted together through the agency of gusset plates. The exterior covering is fabric. This type of fuselage or, for that matter, any riveted frame alloy type pays for its weight saving by increased cost of labor and the alloy material. Refer to Figure 61.

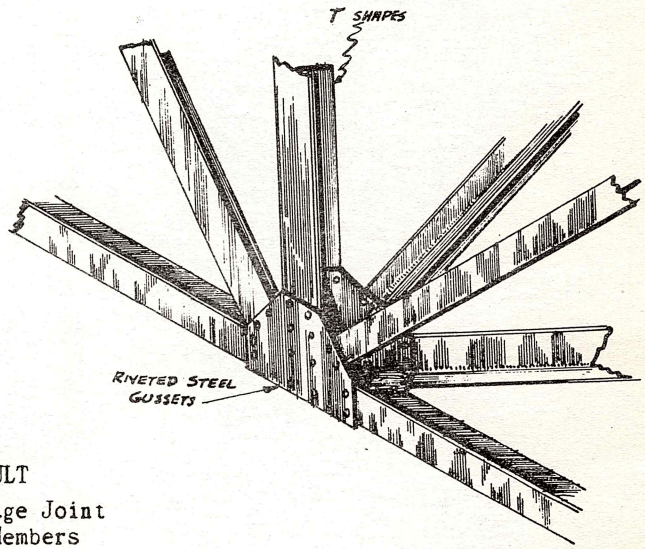


Figure 61

VICKERS - WIBAULT
Detail of Lower Fuselage Joint
Using Solid Rolled Members

The British method of strip construction is widely used by Boulton and Paul and the Bristol and Gloster organizations in England. Fuselages of this sort are extremely light in weight and very strong with high strength tensile steel formed into a multiplicity of structural members as the elements of fabrication. Figure 62 illustrates the salient features of a joint. The material is all rolled on roller dies and is of light gauge steel, preferably higher than 24 gauge. The rivets in any instance are extremely small, ranging from 1/16 down to 1/64 inch in diameter because of the high strength.

The element sections of this form of construction may be varied to suit the conditions. The joints are all held together by a system of gusseting plates of steel. Obviously this method of construction is expensive except in quantity production. Yet numbers of military planes for the R.A.F. have been widely used under all sorts of service conditions, each type being varied in design and size. In spite of small production numbers, planes of this sort are built competitively with other forms of construction since a great many of the operations are done with machines. Once the initial patterns and the requirements are worked out, the production problems have not apparently been greater than in any other existing type. Fuselages and wings of this sort have the advantage of part replacement in event of damage.

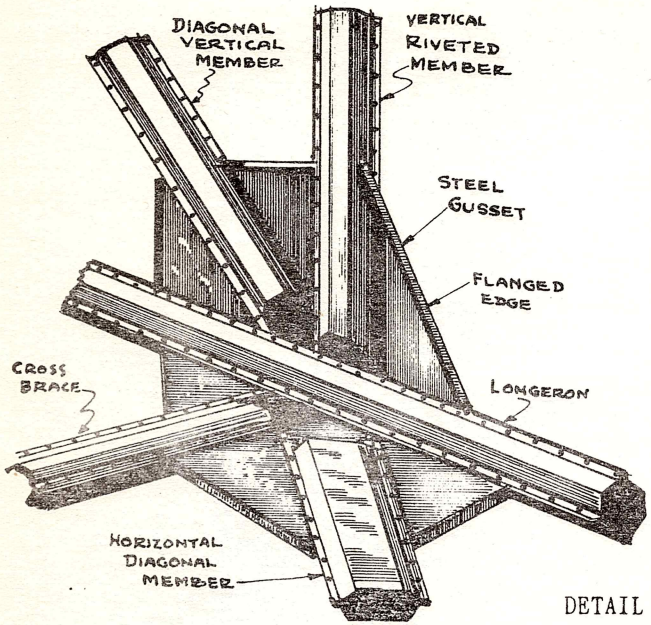


Figure 62

DETAIL OF LOWER FUSELAGE JOINT
USING ROLLED STRIP METAL

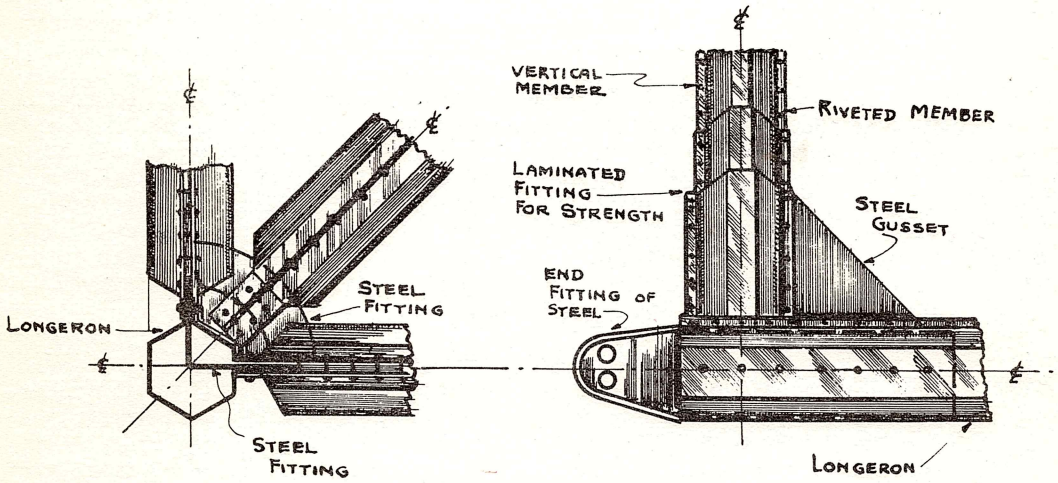


Figure 63

DETAIL OF ROLLED STRIP LOWER
FUSELAGE LONGERON INTERSECTION

THE WELDED STEEL TUBULAR FUSELAGE

This type of fuselage, perfected by Fokker in Germany during the War, has been widely used in the U. S. A. The advantages are manifold, plus a cheap cost. The structure is strong and durable when correctly welded, and capable of being repaired easily; hence its wide adaptability to commercial operations.

The welded steel fuselage is not obsolete. For strength, it has much to offer although the corresponding weight is greater. However means for its production are inexpensive. Therefore the use will continue for many years. Any form of welded structure has much to offer to the production of a cheap structure, the only requirement being a jig plus a cutting machine for the tubing and the fusion apparatus. Welded parts are used in many stressed skin aircraft, such as motor mounts and landing gears; and for certain kinds of work, welding is much desired over riveting.

There are two types of welded structures, the first uses the all tubular members in a system of Warren trussing and the second uses a system of the Pratt type of truss employing wires for the diagonal tension members. Curtiss and Douglas have produced fuselages of great strength using the latter member, while Consolidated utilizes the heavier Warren truss fuselage. Each has certain advantages over the other. For general use the wire braced fuselage is ideal when braced with tie rods that can be adjusted for any signs of slackness.

Two examples of welded steel tubing fuselages are shown in Figures 64 and 65. The one is gas welded, using a Pratt truss system with wires or tie rods; and the other is steel tubing welded electrically, employing the Warren truss system.

In any form of fuselage construction the use of diminishing gauges and diameters is utilized for lightness and strength. Joints when connecting two sizes of tubing or gauges must be of the long fish mouth type and welded securely. The strength of any fuselage depends on its resistance to bending and torsion. If poor jointing is present then the strength is no stronger than the weakest weld.

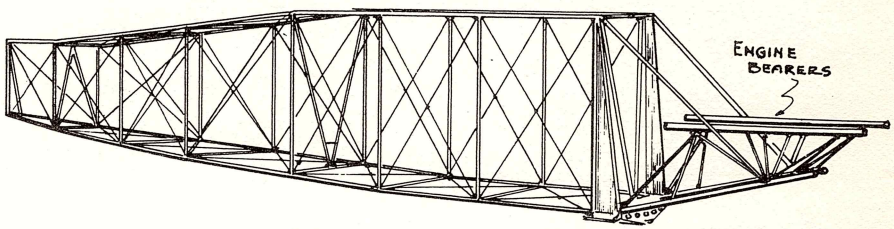


Figure 64

CURTISS WIRE BRACED PW8-A

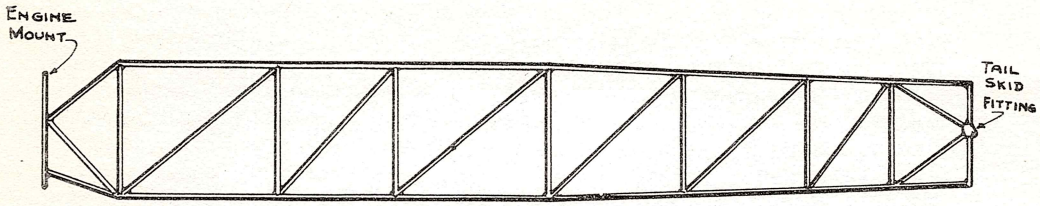


Figure 65

BOEING P-12 TYPE
ELECTRIC WELDED

The strength of the welded fuselage in either gas or electric form is the joint and the intersection. The correct method of joint design so as to preclude the possibility of cooling strains, inducing cracking of the weld, is something to be carefully considered since a weld in tension is only about 2/3 the strength of the original material.

For joints in steel tubing the point of the minimum strength and hardness of the base metal is about 1/2" from the weld center. Tee form of joints when loaded up to high bending stresses, with gussets at the joints for reinforcing do not have any greater degree of strength since the correct method would be to use a slightly larger diameter tube. Where stresses are low a strap reinforcing is better; that is, the strap is welded into the joint as shown in Figures 66 A and B.

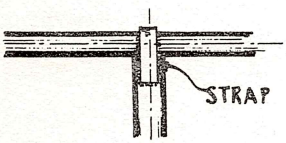


Figure 66-A

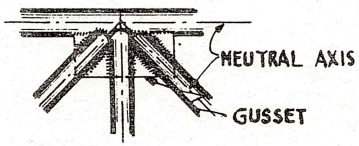


Figure 66-B

The advantage of gussets is not very great. They increase the weight, and cost more to weld, layout, etc. Good joint connection can obviate the need for gusseting. The whole secret of good jointing is to prevent the collapse of the tubes in the joint, and the most gusseting can do is to contribute a net 20% increase in strength. Gusseting is most efficient when one plate connects all the tubes through means of a saw cut in the ends.

No established rules exist for the design of welded joints. The Air Corp recommends 15,000 pounds per square inch in reduction for chrome moly steel and about 4500 for 1025 steel. A good weld is generally very strong and hard in itself. Tack welds and cooling distortion are individual problems that must be solved to produce good work. The jig must at no time allow expansion or distortion. Heat treatment of welds can produce extreme strength, but for large structures this is prohibitive.

ENGINE BULKHEADS AND FIREWALLS

These members of the fuselage must invariably be of heavy construction. The usual way is to build a heavy bulkhead of 12 to 14 gauge material, channel framing member and the inner plate being of light gauge stiffened dural. The outer bulkhead carries the engine mount and the inner plating is stiffened against vibration. Control openings are grommeted with ferrules. The engine bulkhead must be strongly built since it carries heavy loads both fore and aft in a shell type of fuselage. With large loads high concentrated means must be made to distribute the loading to the thin shell structure gradually; hence certain forms of laminations or sheets of varying gauges are used. These bulkheads all utilize some sort of channel section formed to the correct shape; made in several pieces; and joined by splice plates for low cost in production. The material is usually 24 SRT heat treated for strength.

Corrugated engine bulkheads have been used with good success. These are merely channel formers with a corrugated firewall stiffened against vibration at intervals. The channel outer members carry the engine mounts and heavy weight. The Junkers planes utilize this sort of firewall successfully.

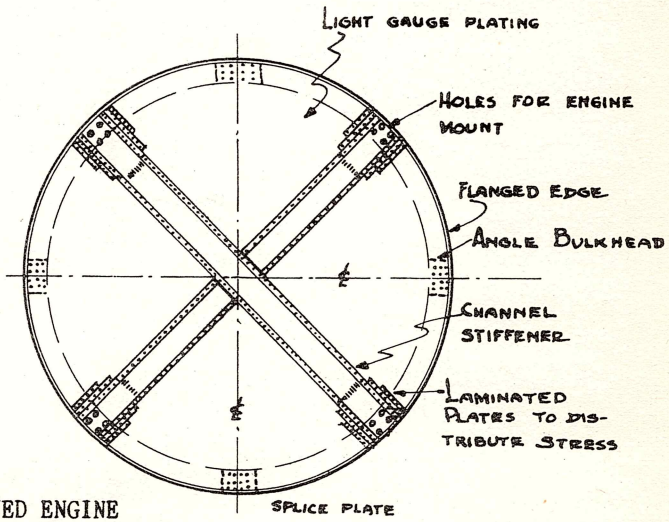


Figure 67

EXPERIMENTAL STIFFENED ENGINE BULKHEAD AND FIRE WALL

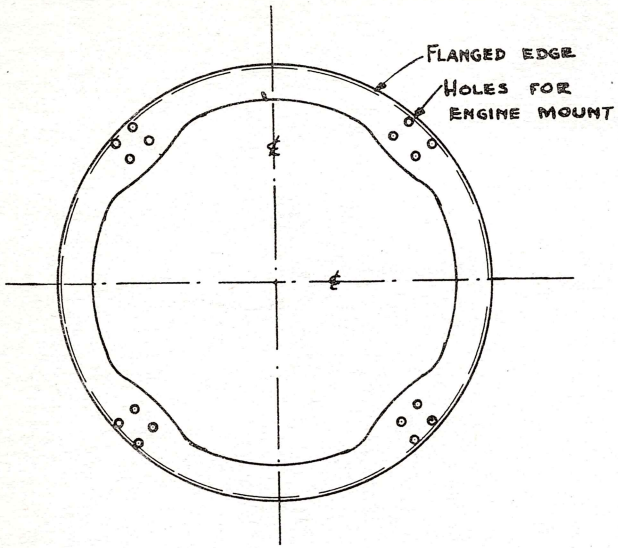


Figure 68

NORTHROP TYPE OF ENGINE BULKHEAD AND FIRE WALL

This frame is made fireproof by the inside plate being riveted to the outer bulkhead and the plate is stiffened. The fire wall is light gauge dural.

CHAPTER VI

WING CONSTRUCTION

WING RIBS

Perhaps no other subject has received in modern aerodynamic structural design, the research and experimentation as the various forms of wing ribs structures. From the advent of the early prototypes, an unceasing development has been undertaken in the effort to produce wing ribs that have high ratio of strength to weight, cheap cost, adaptability to modern production, and durability.

Various ribs developed from time to time have all, now and then, at one time satisfied one of the above conditions; but unfortunately cannot satisfy all of them at once. Therefore, the rib that comes nearest to satisfying all the above requirements would seem to be the ideal.

Since the advent of the cantilever wing the cost of ribs has steadily increased, because in this form every rib profile is varied; hence the increased cost of an aerodynamically clean wing. The various forms of ribs suitable for various types of wings will now be undertaken in detail.

In rib construction the question of cost is paramount. A built-up rib is costly from the labor standpoint and the accuracy required for similarity to its similar ribs. On the other hand a die pressed rib is extremely accurate and each rib is similar; and the actual cost of production and the time is little. However the increased cost of the die militates against this form, unless large production is available. This is especially true when using a tapered airfoil. Tapered airfoils increase the cost of rib fabrication enormously. Unfortunately any other recourse is just as costly, with the stressed skin wing rib costing the most. In a braced wing the uniformity of many of the ribs makes production cost by dies a tempting answer. The Douglas Company employs a system of rubber dies for cutting dural of light gauge. These dies are very efficient and economical in cost.

Figure 69 illustrates a rib used by the Consolidated Aircraft Co. The rib is flanged all sides $\frac{1}{2}$" and formed in die press. The holes are spun out with riffled spun edges for strength.

Figure 70 is an experimental rib built of steel channel spot welded construction.

Figure 69

CONSOLIDATED AIRCRAFT

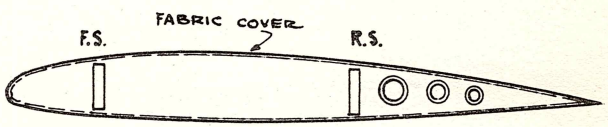


Figure 70

EXPERIMENTAL RIB

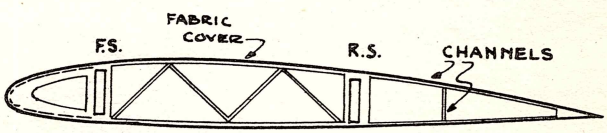


Figure 71 is an experimental all dural rib of flat sheet with flanged $\frac{1}{2}$" edge. The holes are spun out and the edges riffled for strength.

Figure 72 is a rib from the Curtiss Robin monoplane built by Curtiss Wright. The rib weighs .60 of a pound with flanged edges, and is pressed from dural sheet. The members of the truss and the edge of the cut-outs are grooved for strength.

For the sake of simplicity the spar cut-outs are shown at 15 and 60% of the chord. In the actual ribs, due to design variations, this spar spacing will vary.

Ribs of these types are used with wooden spars and held to same by nails through turned flange pieces.

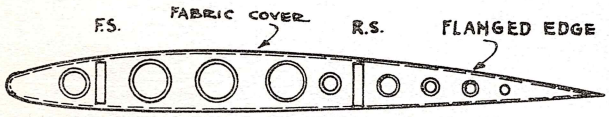


Figure 71

EXPERIMENTAL RIB

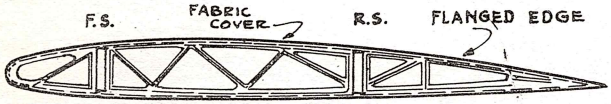


Figure 72

CURTISS-WRIGHT
CURTISS ROBIN RIB

Figure 73 is the rib used by the Grumman Company in the SF-1 Fighters and amphibian aircraft. The rib is of steel, formed as shown, and electrically welded into a sturdy truss. This rib is extremely strong and light.

The Fleet rib Fig.74 is made of formed dural with a crinkled flange to facilitate bending. The ribs are of .014 dural alloy heat treated.Cap strip is 1" in width overall and 21/32" deep in section. Weight is 5 oz. for a 48" chord. Leading edge is formed of .030 heat treated dural.

The special rib shown in Figure 75 overcomes the difficulty of forming a flanged angle over a long radius. The angle is cut out,as shown, and riveted to a pressed dural blank shear member forming the airfoil. The holes have a grooved edge. The flanges are riveted to the shear member.

Figure 76 illustrates the truss steel welded rib. These ribs are very strong, light and ideal for fast production and good accuracy.

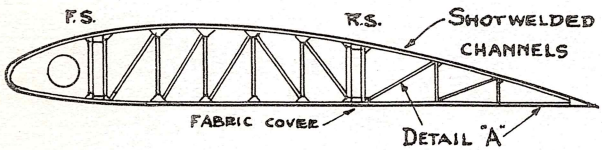


Figure 73

GRUMMAN

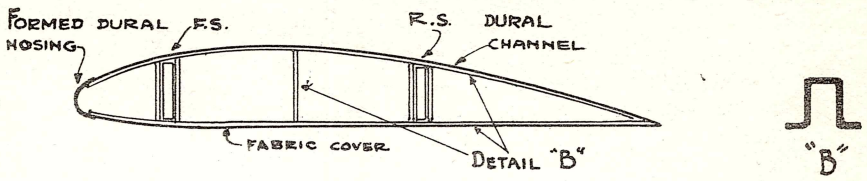


Figure 74

FLEET

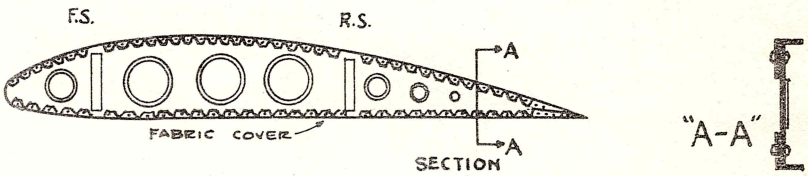


Figure 75

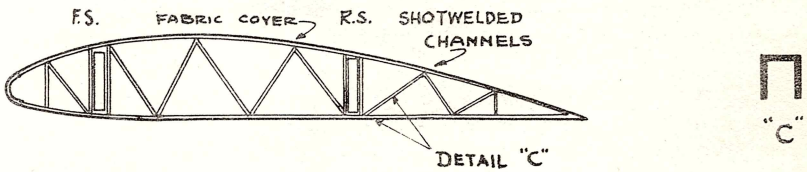


Figure 76

AERO TRUSS

THADEN CANTILEVER METAL WINGS.

The Thaden all-metal dural alloy wing has proven to be a very satisfactory method of wing construction. This wing is a composite construction of metal members all riveted together into a homogeneous structure. Thaden has constructed three planes using this method that in test flight vindicated the design choice.

The Thaden wing is a structure depending on the rigidity of a box section in the center part of the wing. The compression members are corrugated with a layer of corrugated metal running transversely with the span on the inside of the wing. This inner corrugated sheeting extends down around to the bottom of the wing, forming a box section.

The covering is corrugated except the leading edge, which is smooth. The corrugations on the covering run crosswise to the transverse inner dural sheeting, and the whole structure is riveted together. This makes an extremely strong wing structure, whereby the bending is resisted by

the inner skin forming the box section, and the drag forces are absorbed by the outer skin in its corrugated form.

Since this wing uses the cross members, it likewise combines the advantages inherent to multicellular construction; yet at the same time, from a labor standpoint, eliminates the excessive amount of small part production and assembly. The compression corrugated members are spaced about 24 inch centers at the closest, and spaced wide where the loading is less. The spar of the Thaden is simply an I beam built up of heat treated dural and riveted to the structure. The main resistance to bending lies in the center box section and the skin strength.

The nose and the trailing edge construction are of the orthodox manner with a shear member taking the nose forces. In reality this wing has a formed box type of nose section adjacent to the center box section, and has proven to be extremely rigid under flight performances. See Figure 77.

INTERNAL STRUCTURES

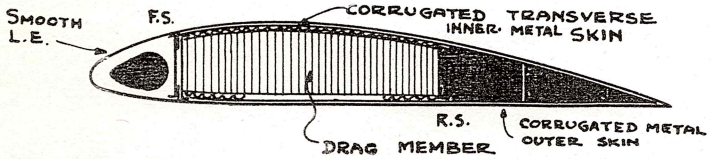


Figure 77
THADEN

JUNKERS SPORT PLANE

As a comparison to the few examples of metal sport planes produced in the U. S. A. the Junkers is a good example of wing construction. The entire affair is covered with corrugated dural alloy or Electron metal with the corrugations crossways to the internal structure.

The internal structure of the wing is composed of tubes with a corrugated shear member. This structure is further tied together and braced with diagonal grooved members. The bending moment of the tubular spar with a corrugated shear member is extremely high. This structure is extremely strong in torsion. The wing covering is riveted. The internal members are riveted in a jig by a special system of riveting developed by the Junkers Company during the war. This wing is very low in weight and has proven very satisfactory in light plane service. Several examples have reached the U. S. A. The wings are joined to the center section by a special Junkers system of jointing. See Figure 78.

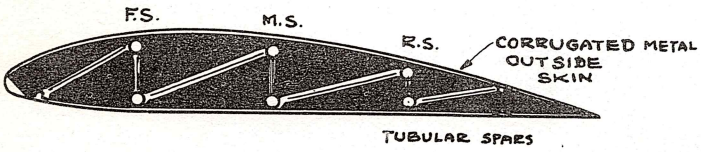


Figure 78
JUNKERS SPORT

The Eastman wing shown in Figure 79 is an example of a multicellular wing adaptable to external bracing with a corrugated covering riveted to the inside metal structure. The inner structure is lightened by riffled edge holes. Each diagonal member is riveted to the wing top and bottom. This type of wing is a modification of the multicellular wing, although accomplishing the same purpose by a reduction in cost of the numerous small parts in the orthodox construction.

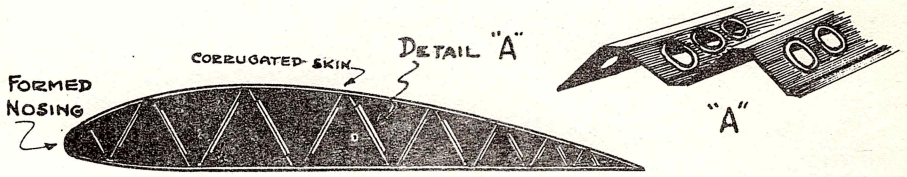


Figure 79

EASTMAN

TOWLE

The Towle wing is similar to the Eastman wing. The Towle wing makes use of a similar construction save the inner shell structure shear members are corrugated, giving added strength;and at the apex of each cell, the wing is further stiffened by a rolled dural section to which the corrugated outer covering is riveted. The Towle wing is a fine example of cellular wing using an internal structure with transverse stringers and a corrugated covering to resist torsion and bending forces. The corrugated webs are lightened with circular cut-outs. See Figure 80.

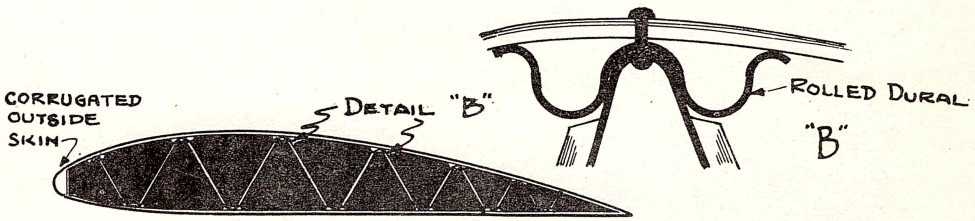


Figure 80

TOWLE

Figure 81 is a pressed Alclad rib used in the wing of the Loening amphibian observation airplane. The rib is pressed from sheet Alclad and is very light.

Figure 82 is a pressed rib of alclad with riffled cut-outs and grooves for additional strength. This rib is used on a very wide chord wing and has proven satisfactory in service.

Figure 83 is a rib similar to that used in the Douglas DC-2 Airliner. The rib is merely a flat profile with pressed lightening holes with riffled edges. This rib is very light and made in four pieces with flanged edges for riveting to the structure and the wing skin.

Figure 84 is an experimental rib produced by the Keller-Berchereau firm in France. The rib is produced in three parts, and the edges are flanged for riveting to the metal skin. Lateral stiffeners help carry the skin of the wing and also tie the ribs together into a multicellular structure.

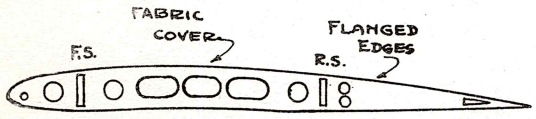


Figure 81

LOENING

Figure 82

ALCOA PRESSED RIB

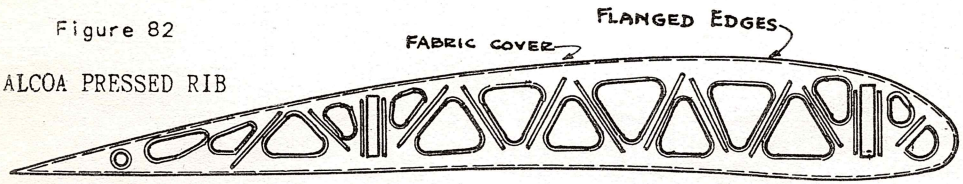
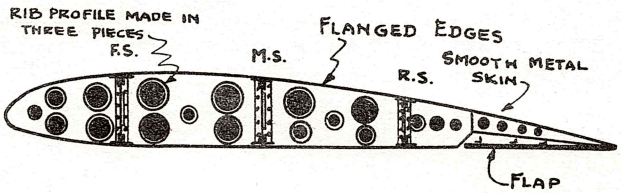


Figure 83

MULTICELLULAR RIB



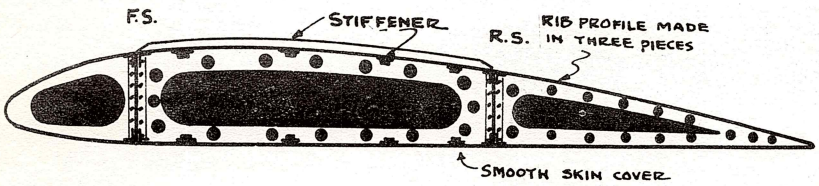


Figure 84

KELLER - BERCHEREAU

Figure 85 is a rib similar to that utilized in the Capelis Experimental Air Transport plane. The rib is built in several sections and riveted to the skin.

Figure 86 is a rib developed by the Consolidated Aircraft Company for use in large ocean going flying boats. The rib is built of an extruded rolled dural cap strip on top and bottom, and the truss members are fitted to these by means of a special cast forging piece. This rib has proven extremely durable and efficient in service.

Figure 87 is a special experimental rib built of rolled cap strips shaped in vee form with rolled edges. The rib is made of steel of high tensile strength and light gauge. The truss members are likewise the same section. The rib is covered with fabric laced to the cap strips. The compression strut is simply a flanged stiffening channel with cut-out holes and secured to the spars.

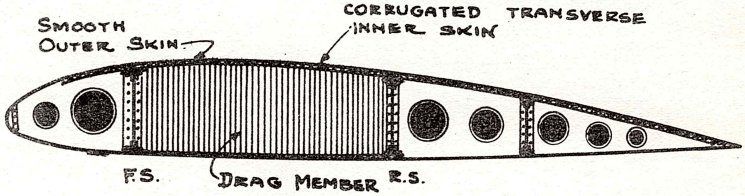


Figure 85

CAPELIS

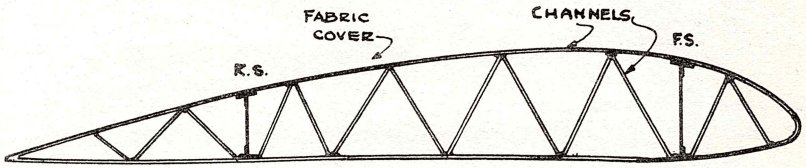


Figure 86

CONSOLIDATED

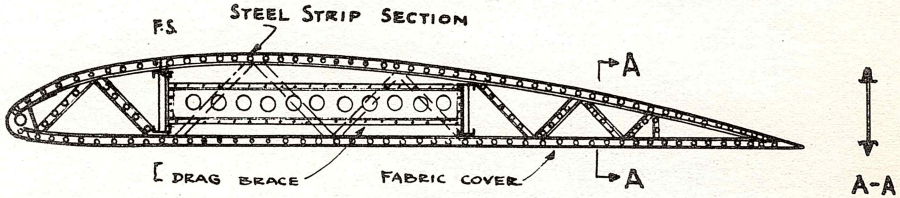


Figure 87

ROLLED STEEL STRIP RIB

The success of the Junkers large transport planes is exemplified in the adherence to the original construction principles incorporated in the war time planes. This arrangement has proven to be a sound engineering development.

The Junkers wing is composed of seven tubular members which are joined together in a truss system by a number of triangularly arranged dural strips or tubular members. These members hold the structure from collapsing. The outer skin is corrugated, and this reacts against the drag loads while the tubular structure acts as the basic structure to resist bending and torsion.

The wing is fastened to the fuselage stubs by means of special adjustable fittings made of steel. The Junkers truss is extremely strong although it does employ the exclusive German method of inside riveting a rather difficult procedure; yet failure has seldom resulted in these rivet joints. Figure 88 shows the basic wing structure.

The Ford wing rib truss is shown in Figure 89. The success of the Ford Trimotor augments well for this type of construction which is riveted throughout. The truss is a multispar arrangement with truss members of channel and angle section riveted to the corrugated wing skin covering and the spars.

The Boeing 247 type of transports employ a wing rib truss similar to that shown in Figure 90. This wing is composed of a metal skin with transverse stiffeners at the point of contact of the truss members which are riveted to gusset plates. The wing is further stiffened by angle and channel members running around the contour of the airfoil and riveted to the skin as well. The wing is of the two-spar type, using a truss spar arrangement with a top and bottom channel flange member, and gusset plates holding the shear members of the wing spar truss. This arrangement has proven extremely efficient in air line service conditions and everyday use.

The Martin Clipper type flying boat employs a built-up rib of dural channels for the cap strips with a riveted cross bracing system of dural tension members stiffened by forming. This rib is very light for its great strength. The schematic detail is illustrated in Figure 91.

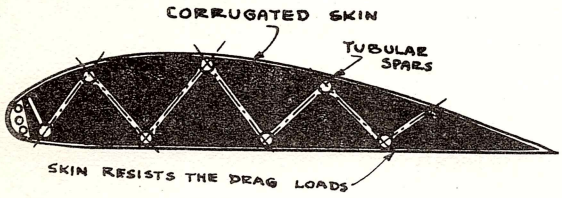


Figure 88

JUNKERS

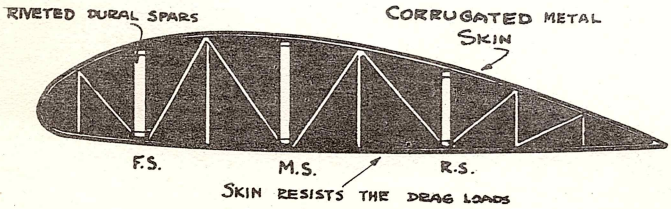


Figure 89

FORD - STOUT

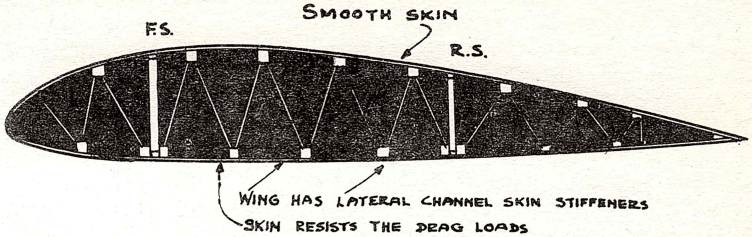


Figure 90

BOEING

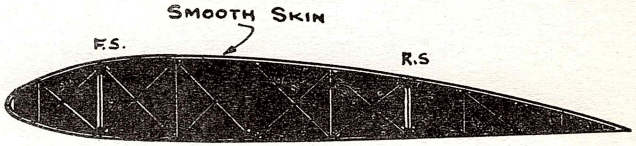


Figure 91

MARTIN

Figure 92 illustrates a multicellular rib with transverse stringers and a trailing edge flap. The web is lightened by circular cut-outs, the rib profile being produced in several pieces with flanged edges and the entire assembly is then riveted together. Multicellular simply means a part consists of many cells or more than one cell.

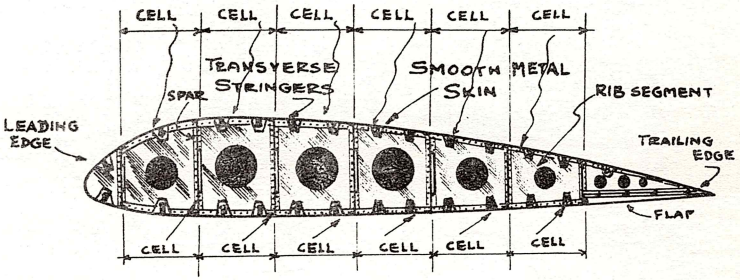


Figure 92

EXPERIMENTAL MULTICELLULAR RIB
WITH MULTISPARS

This type of rib, shown in Figure 93, employs a full under skin lateral corrugated reinforcement with a smooth outer skin. The bottom of the wing is reinforced with channel transverse stiffeners. The rib is made in three parts.

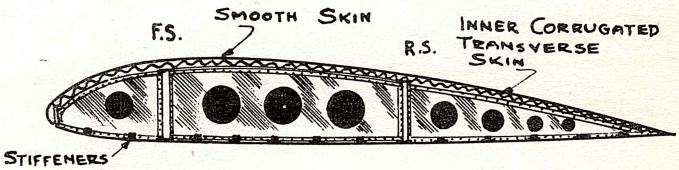


Figure 93

EXPERIMENTAL RIB

In Figure 94 is a typical rib construction employed in the structure of the Northrop multicellular wing. The rib profile is built up of multiple flanged plates which are riveted to the skin and the transverse spar members. The profile is lightened by circular cut-outs. The wing skin is smooth and is stiffened by "Omega" section transverse stringers spaced as shown.

For strength, the wing has more lateral stringers on the top surface than on the bottom, because the flight loads are greater than the landing loads. The lateral stringers are in long length and riveted to the wing skin. The rib profile has cut-outs on the rib profile pieces through which the lateral stringers pass. In this manner greater strength is secured in bending. The cut-outs are cut when the rib profile is being manufactured.

Figure 95 is the type of wing rib employed on the Vultee V-1-A. This wing employes a double spar system. The spar system forms the ends or sides of a box with a corrugated transverse under skin top and bottom to augment the strength in lateral bending and torsion.

The ribs are built up of three pieces, flanged on the ends, and the whole riveted together into a homogeneous structure. Circular cut-outs are utilized to gain lightness and cheap production.

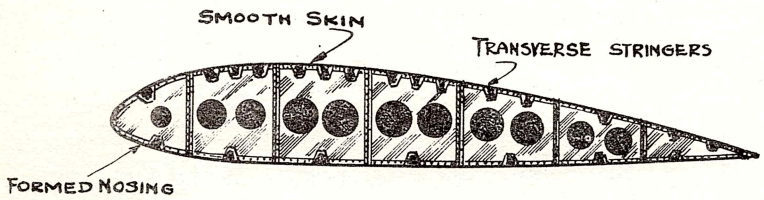


Figure 94

NORTHROP TYPE RIB

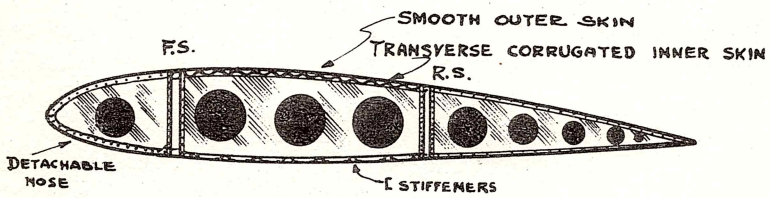


Figure 95

VULTEE TYPE RIB

METAL WING RIBS

The Douglas TWA Airliner employs a multicellular wing of very efficient metal construction. A section of the center section is shown in Figure 96. Note that the center section utilizes the strength of a sheet of corrugated dural in the top plane of the wing truss system.

The ribs are composed of sheet profile members with circular lightening holes and a stiffening groove running vertical down the center of the sheet. The rib profiles are made in several sections, and all flanged and riveted together in a homogeneous assembly.

To further stiffen the wing between a rib profile sheet there is a truss rib member that ties the three spars together. This construction makes for lightness with great strength, and at the same time preserves the profile. The wings of this plane are so constructed that the skin carries a large portion of the load. The wings are covered with dural 24SRT ranging in thickness from .02 inches to .029 inches.

The AMIOT wing is an example of a multispar metal and fabric wing. The wing structure is composed of three metal spars arranged in a truss system. The skin is laid over this structure and further stiffened by the lateral stringers of channel shape riveted to the under size of the skin. The trailing edge of the wing is fabric covered over a metal riveted structure. This wing is a good example of metal and fabric wing. The leading edge is preformed metal. See Figure 97.

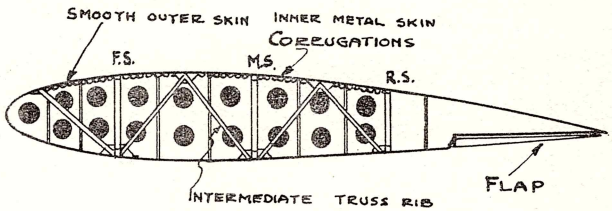


Figure 96

DOUGLAS CENTER SECTION RIBS
DC-2 AIRLINER

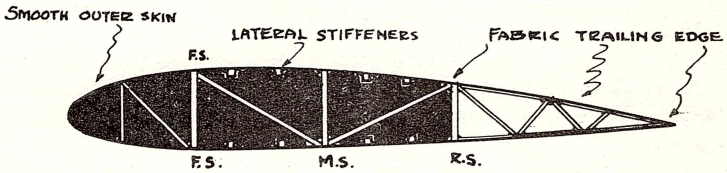


Figure 97

AMIOT CANTILEVER METAL WING

The rib shown in Figure 98 is an example of the construction of a good strip steel rib. This rib is of HAWKER design, and is very light with great strength. The rib is built up of strip members of the shapes indicated, and all riveted together with tiny steel rivets. Ribs of this construction are very sturdy, and are used extensively by the R.A.F.

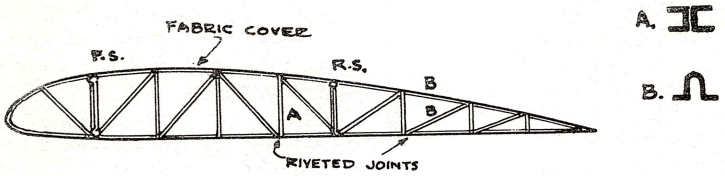


Figure 98

HAWKER STRIP STEEL RIB

COVERING

The wing skeleton must be covered with either fabric, plywood, or metal. Fabric is laced on by passing heavy stitching thread around the members of the ribs and lacing the structure down taut. The rib lacing is then covered with tape and the whole doped and sprayed with the desired finish.

In order to expedite the application of fabric on metal ribs, the Fleet aircraft utilize a self tapping Parker screw with a circular covering patch that goes over the head of the screw. These patches are doped into place and make a substantial method of covering a metal wing without lacing the fabric to the spars. Parker screws, being self tapping, may be easily removed and reused when the wing is re-covered. The Parker screw can only be used in a metal flanged rib.

Metal wing covering is much the same as the shell plating of a metal fuselage. In the majority of large wings the contours and the radii are large; therefore the sheets may be sprung into place and riveted to the internal structure. For the nose sections, however, specially formed pieces must be used since the radii are sharp,and this part also requires the stiffness of a preformed piece for additional strength.

Metal covering is most advantageously applied in the largest sheet sections possible, because the greater the area covered by one sheet in a multicellular wing, the greater the strength. The joints should be alternated if possible. In applying the covering the nose section out to the tip of each wing is generally laid on and secured in place at alternate intervals. It is held temporarily by bolts or screws and then riveted alternately,until the whole structure is riveted up. Then the wing covering itself is applied from the root section outward since this is the easier method. The jointing must be of such design that the use of squeeze riveting guns can be employed or single shot riveting in places where it is possible to back up the rivet head. Special dolly tools are sometimes required for these operations. Since the final sheet is the most difficult to rivet and seal up the wing, this sheet is generally screwed into place with special sheet metal screws.

Wing covering is of light gauge. The lighter the gauge the more chance for waviness, which detracts from the efficiency of the airfoil. Flush riveting should be used on all parts of the wing even though the initial cost is greater. Exposed rivet heads increase the drag of the wing alone about one per cent. On the Martin YB Bomber a covering of 18 gauge is used while on the smaller pursuit ships, such as the P-26A, 22 and 20 gauge is used extensively for covering.

Tightness of all riveting joints in wing construction is essential, because a loose joint will seriously affect the wing's strength. Moreover, since the wings are always subject to fatigue stresses any form of looseness in a metal riveted joint may lead to failure in flight with consequent seriousness.

Metal wings for normal load factors will approach 2 pounds to the square foot of area. Multicellular wings will slightly better this figure in wings of moderate size.

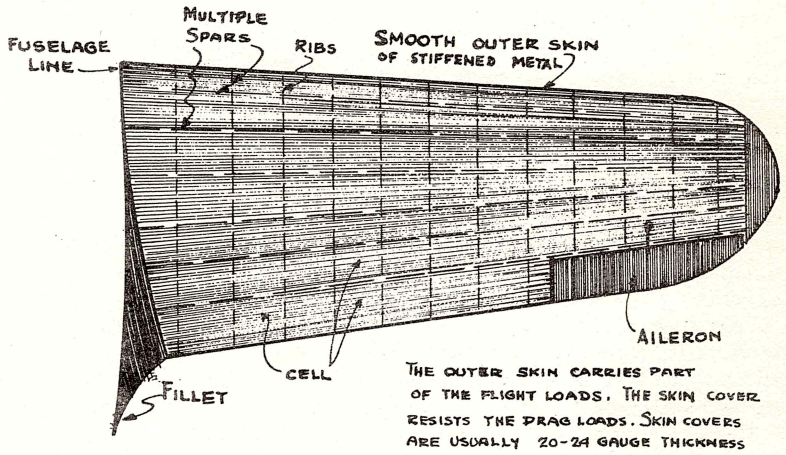


Figure 99

RIB AND SPAR ARRANGEMENT
IN MULTICELLULAR WING

AILERONS

Metal ailerons are nearly a necessity for aircraft operating under combat conditions, because of the danger of fire and subsequent loss of the use of the surface for control. However at high speeds the need for both static and flutter balancing has necessitated the use of fabric covered ailerons to cut the weight, so that the balances, which are nearly always heavy, may be reduced. The Northrop uses a fabric covered aileron as does the Douglas DC-2. The ordinary flutter balance, as it stands, is made of lead and weighs as much as the aileron; hence a heavy aileron means an increase in weight of the flutter balance so the reversion to a dural covered frame fabric is obvious.

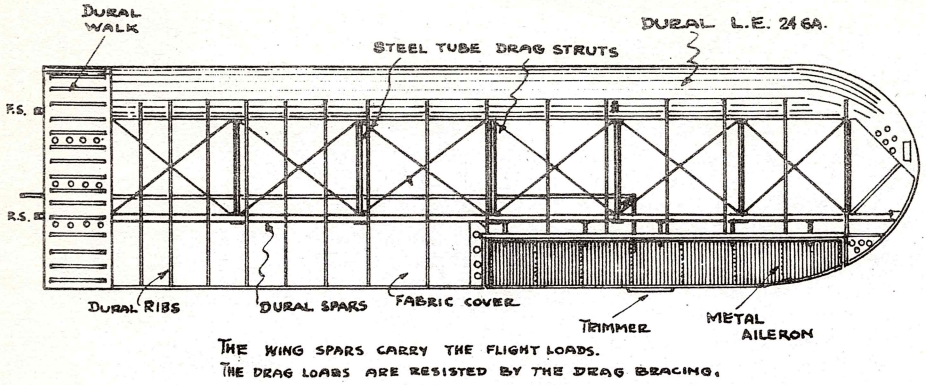


Figure 100

TYPICAL FABRIC WING STRUCTURE
METAL RIBS AND SPARS

Similar Structural Arrangement for Wooden Wing and Fabric Cover or with Metal Ribs and Solid Wood Spars

However on light commercial planes, in the effort to cut production costs, and where large aileron numbers are possible to be manufactured, metal ailerons have made much headway. The Waco aircraft all employ a shell covered metal aileron. This aileron is very light and is comparatively small; hence the wide use.

On the other hand, Boeing has used metal ailerons extensively on all military aircraft. The subject is a debatable point as yet, and the best practice can only be determined under extensive service conditions. Outside of flutter balancing at high speeds, the metal aileron is distinctly the best in many ways. Various types of ailerons are shown in the illustrations herewith as well as a brief description of each.

The Curtiss Tanager floating tip aileron is shown in Figure 101 and illustrates the method of composite aileron construction using a wooden spar and ribs, with metal nosing and trailing edges and covered with fabric.

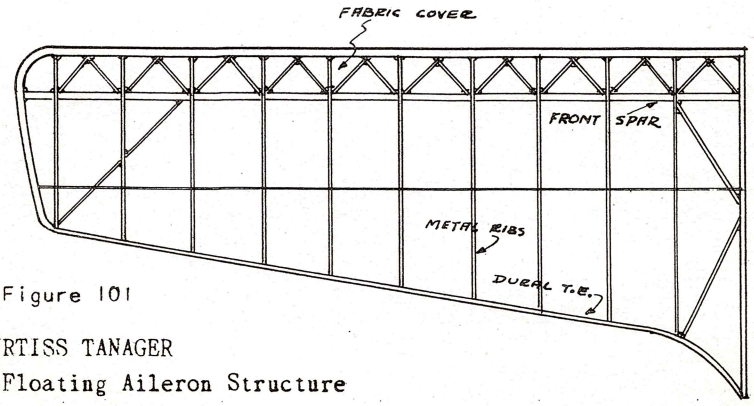


Figure 101

CURTISS TANAGER
Detail of Metal Floating Aileron Structure

The fabric covered aileron structure shown in Figure 102 is another example of welded steel framework for the aileron control areas. The aileron spar is of steel tubing of light gauge with various rib and bracing members welded thereto. The trailing edge is of light steel small diameter light gauge tubing. The ends are braced with lightened gusset plates. The hinges and the actuating arm are likewise welded to the aileron spar. This type of construction is not of the Frise type.

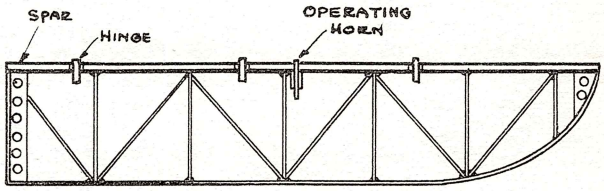


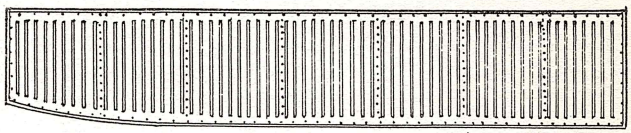
Figure 102

FABRIC COVERED AILERON STRUCTURE
WELDED STEEL, WOOD OR RIVETED DURAL

In Figure 103 is shown the Boeing type of aileron construction using a metal corrugated surface over a dural frame. The entire surface is riveted to the frame and the outer shell is preformed to whatever profile is required. These surfaces have proven to be ideal under difficult service operations and have stood up well.

Figure 103

BOEING P-12 AILERON



STRESSED SKIN CONSTRUCTION

This form of wing construction is obviously the most modern and advanced practice. The construction in multicellular form has much to recommend it from the efficiency of the weight to strength of the structure. Yet this method, while obviously efficient from a weight reason, is rather expensive in actual production cost. See Figure 99.

This type of construction limits the basic type and the designs that one factory may produce with a minimum of cost since it is not versatile to rapid adaptation to various types without a great change in tooling up cost, die cost, material cost, etc. Once, however, a given type is basically standardized, the production cost is lowered appreciably but

still too high when compared to the economy of the welded steel tubular construction with wooden wings, because the multicellular construction necessitates the use of a high grade dural alloy.

Multicellular construction in the present state of the art is only possible through the agency of riveting, which is a slow process when compared to welding. Until the advent of development in fusion welding, with its greater speed of production and lower cost, the multicellular type of construction using dural alloy is the most expensive.

The original engineering cost of a plane of multicellular construction is correspondingly higher over that of composite construction by reason of the great multiplicity of individual parts making up the structure, and the original cost of producing the patterns and the dies and means for making the same.

Multicellular construction is primarily dependent on a thin shell plated structure which carries major parts of the tension and compression loads in the skin and transfers the shear loads to an internal cellular structure. As the box section is inherently the strongest and the lightest in carrying loads of any sort, hence the adaptation of this principle in multicell wings and forms of fuselage parts.

Among the best examples of a multicellular wing type is found in the design of the Northrop metal aircraft designs of transport planes. These planes show an enormous payload carrying capacity at high speed.

The structure of the Northrop multicellular wings employ the lightest dural alloy developed in the U. S. A., namely, 24SRT Alclad in light gauges. The wings in cantilever form weigh a trifle over two pounds per square foot of area. This low weight is possible by using the lighter alloy over that of 17ST and 17SRT or 17SO formerly used.

The spacing and the sectional shape of the stiffeners are such that a high weight to strength ratio is possible. The stiffeners are more closely spaced on the top skin than on the bottom and the same formed of special section. All sharp profiles are preformed for the fillets, the leading edge, and the tip sections. It is claimed that since strength is in the metal skin cover of 24SRT Alclad that a visual inspection indicative of the condition of the wing is possible at all times. The shear loads are carried by the lighter metal cell structure and the rib profiles, and these are lightened to further decrease the weight.

The wing stubs are the same basic construction as the wing save that the gauges are heavier and the stiffeners are more closely spaced. If it is desired to use a retracting gear in a wing of this sort some form of spar construction will be required in the stub section to carry the loads and the wings will still be of the multicellular type.

The majority of metal wings suffer at present from unevenness of the wing profile because of the metal stretching while working or not being correctly applied or preformed. With multicellular wings the close spacing of the lateral stiffeners and the ribs cells obviate this trouble; and consequently the wing is of very smooth contour, which makes for efficiency in flight conditions.

COMPOSITE CONSTRUCTION

The composite wing construction is still widely used, because as yet the production of metal wings in the U. S. A. and the weight for reason-

able strength is still a highly specialized problem. Composite structures will be widely used for many years. As a matter of fact, to gain lightness the trailing edge of the Martin YB is fabric covered laced to the metal edge of the rear spar. The Northrop ailerons on certain types of planes, to cut the need for excessive counterweighting and flutter balance, have been fabric covered over a dural framework. See Figure 99.

The merits chiefly of composite structure are weight and economy. Fabric doped covering is very durable and will last with good care up to 18 months time in hard commercial service. The servicing cost of inspection for fabric and metal is the same, because all metal areas must be inspected and protected periodically for corrosion, whereas the fabric area must be cleaned from foreign substances contributing to deterioration.

At present the majority of the small commercial planes in the U.S.A. use a wooden wing. This is used mainly for weight and cost. The cost of wooden wings in manufacturing is much less than an all metal wing. With pressed dural ribs and spruce spars an extremely good form of wing of braced construction is possible, such as in the Curtiss Robin. Most wings of this sort (for example, the Fleet) use a metal rib, wooden spars and steel tubular drag struts and steel bracing drag wires. All fittings are of steel.

By reason of the great familiarity of wood work and steel work, wings of this type can be built or repaired with semi-skilled labor. The metal wing, on the other hand, requires a skilled sheet metal worker for repair. The item of part replacement must also be considered in commercial repair work, and also the greater need for specialized tools and methods of repairs.The all metal wing from a commercial standpoint cannot successfully compete against a composite wing at this stage of development.

METAL CENTER SECTIONS

The Vought Corsair uses a special center section developed for the express purpose of maximum vision for the pilot in the center of the wing cellule. This center section uses steel spars that are all riveted together. The weight, while considerable, allows the minimum of area at this point to carry the wing panel on either side. Figure 104.

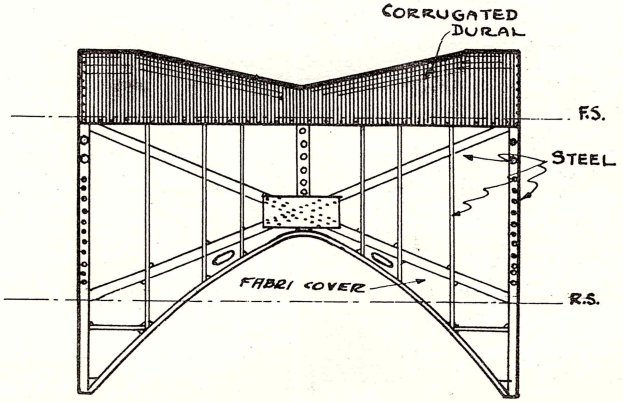


Figure 104

VOUGHT CORSAIR

The entering edge to the front spar is covered with corrugated dural with steel channel cross tie members, plus ribs. The center section herewith is the best developed for vision in a biplane.

COMPOSITE CENTER SECTIONS

The Consolidated Aircraft Trainer employs a composite center section incorporating ample visibility. The spars are of wood with metal rib members. The center of the structure contains a removable fuel tank. The end members are of heavy dural. This center section is very light and strong. Figure 105.

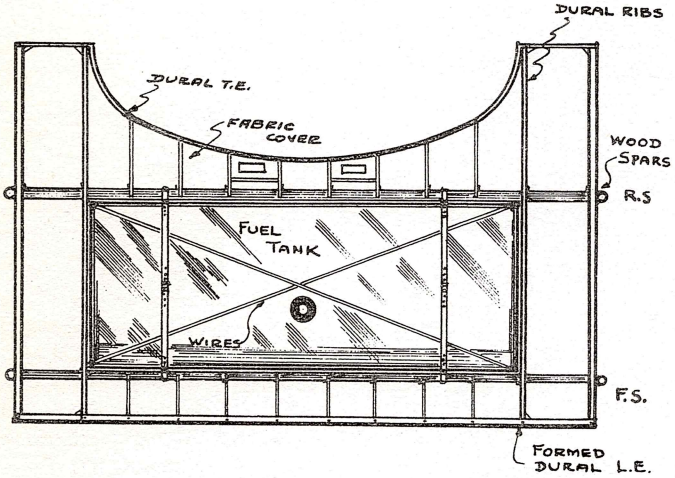


Figure 105

CONSOLIDATED TRAINER

Ailerons of this sort have been used with success. The steel disks are pressed out on a die form, lightened, and welded to the aileron spar. The ribs are merely steel tubing welded thereto and to the trailing edge. A strong and efficient structure.

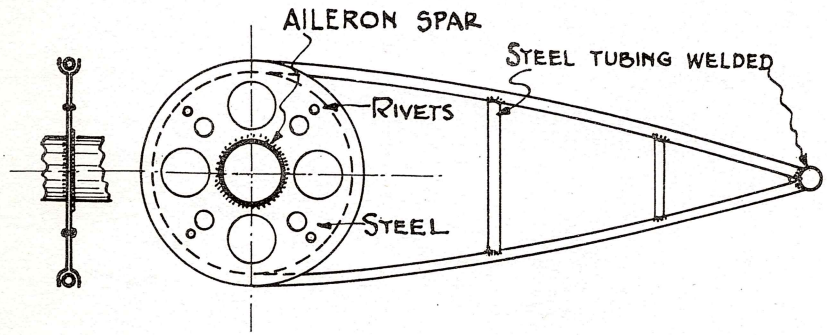


Figure 106

WELDED STEEL AILERON FRAME SECTION

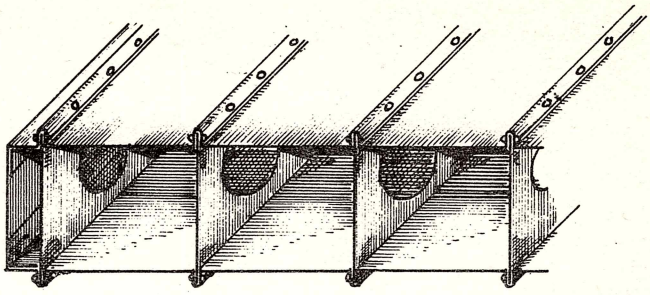


Figure 107

METAL SHELL AILERON STRUCTURE

Aileron structures of this sort have been widely used with success. They are built up of light gauge material and riveted together. The aileron surface built this way is durable and strong. The production is easy since they are composed of simple patterns lightened up and can be quickly squeeze riveted together.

A metal skinning job to be ideal must have all flush surfaces and flush riveting, since the disturbance caused by exposed riveting heads and gauge thicknesses at high speeds disrupts the flow of the boundary layer with an increase then in the total drag. The illustration serves to bring out the method of flush riveting and sheet forming to produce a smooth contour of the wing.

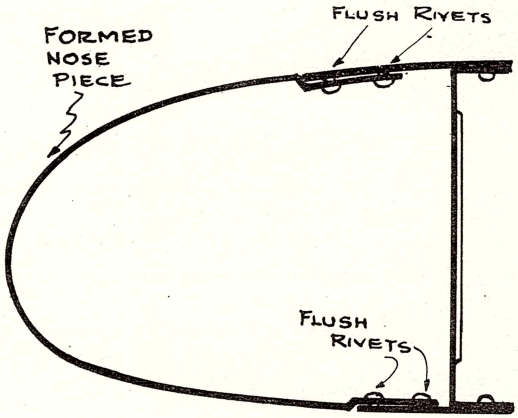


Figure 108

DETAIL OF WING NOSING

A nettle fold is a special machine screw part and fitting that joins two sheets of material together so the joint may be flush. Nettle folds are more costly than rivets. They are used in places where riveting is not possible or in parts that may have to be removed for inspection. The circular top piece, which carries the screw flush, must be flush with the top of the shell plating.

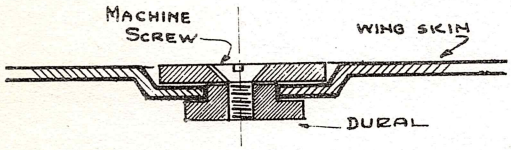


Figure 109

CROSS SECTION OF NETTLE FOLD

Wing flaps in any form add an increment to the weight of the wing; therefore, they must be built with very light structures in order to satisfy this condition. The flaps are made of a single sheet reinforced on the bottom with angle pieces riveted to the underside and with transverse channel members running the length of the top flap surface. The edge is simply folded back for stiffening. Flaps of this sort weigh extremely little and, though they do have to bear considerable air pressure on their surfaces when turned down into the airstream, flaps of this sort have proven very efficient structurally also inexpensive.

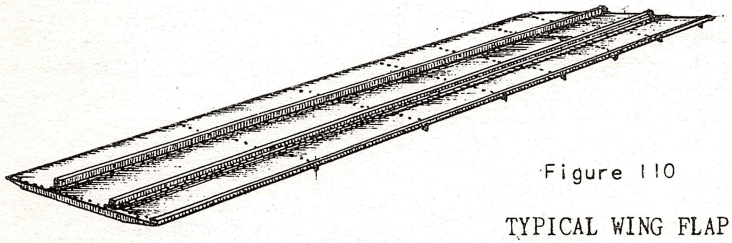


Figure 110

TYPICAL WING FLAP

METAL SPAR SHAPES

Metal spars have been developed in a very great many forms. The metal spar is still a construction problem. The pros and cons for and against the use of two or three spar wings versus the multicellular, multi-spar wing have not been definitely settled, since efficiencies (each comparable to the other in so far as weight to strength ratios go) have been found in structures of both types. Barring cost, the favor in Europe still lies with the two-spar wing in many aircraft; while for certain classifications in the U.S.A., the two-spar type of wing seems to be losing favor.

The only way to determine the merits of each is to seriously study the problem, and then decide from the technical angle which is the most desirable, disbarring the cost. Metal spar construction is costly. It entails numerous small parts as auxiliary members; and the spars, being a resilient member and material, needs to be braced strongly to resist wing torsional forces.

There are several types by which the spars can be classified. The solid structural type, the rolled type in the various forms, and the modifications of the box sections. For strength in bending on a basis of weight, each classification is about equal. From the basis of cost, each will vary from the other. The rolled sections are the lightest although perhaps the most costly to build, by reason of many clips and fittings for attaching the other members of the wing.

No opinion is expressed as to which may be the best type. Each type given has found some practical use, and performs its function better in some ways than in others. Each form of wing airfoil structure alters the spar problem as well. In choosing a metal spar choose one with a minimum of labor, minimum of weight, and a high strength to weight ratio, or a happy compromise of all; and the design thus chosen will not be far wrong.

Being a resilient metal beam, the metal spar is subject to both bending and torsion. Bending is resisted by the depth of the spar and the distance of the flanges from the neutral axis; while torsional forces are resisted by the depth and width of the spar, which should not be greater than five times the width of the upper flange for a maximum of strength.

In many instances the upper flange, which is in compression while carrying the flight loads, is made sometimes of greater dimension (as to depth and size) than the lower flange, which is in tension. Note that when a spar is thus built, the neutral axis[13] does not lie in the center of the top to bottom dimension of the flange distance, but nearer the upper flange; or vice versa, as the case may be.

The spar in Figure 111 represents a built-up spar of two riveted sections, braced with vertical stiffeners joining the top and bottom flange. The spar is rolled from dural alloy with the web being the lightest gauge.

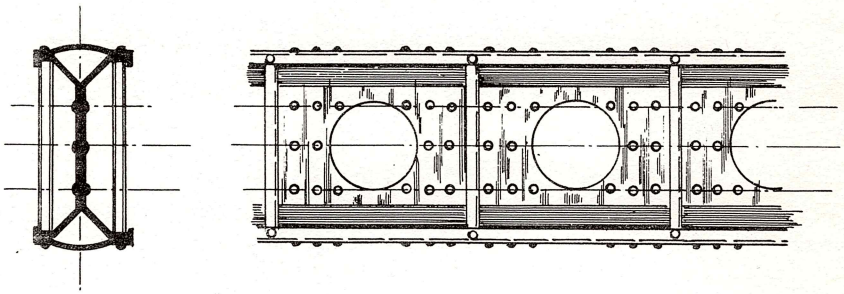


Figure 111

13. The neutral axis is defined as the line through a beam or a sheet where the forces are zero. In a beam this lies usually at the center of the web. In a flat sheet it is an imaginary line in forming about which the outer fibers on one side stretch and the inner fibers compress. At the neutral axis there is neither stretching or compressing. The fibers are at zero stress.

In Figure 112, the section represented is known as the Martin "Eureka" section, and has proven to be very efficient from a strength to weight ratio in all form of construction wherever used. The shape is easily fabricated of light gauge dural with no lightening holes, and is closely riveted.

The spar in Figure 113 is merely two steel tubes with shear members of dural in a Warren truss arrangement, and held by steel fittings, with long rivets merely acting as pins.

The spar in Figure 114 is another example of a spar using steel tubing flange members and a system of Warren trussing, using dural shear members. The web members are held at the apex of the shear members by rivets passing through the flanges of the spars top and bottom, merely acting as pins.

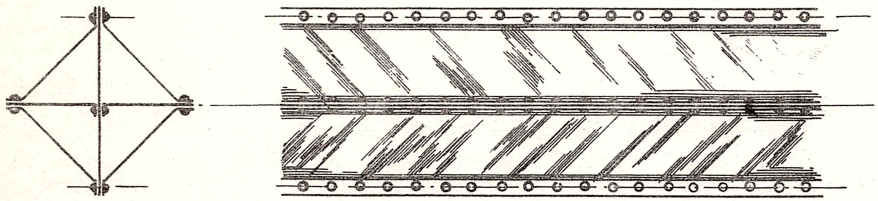


Figure 112

MARTIN "EUREKA" SECTION

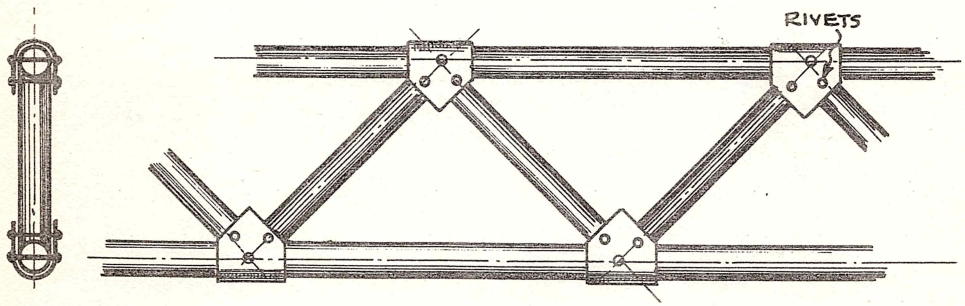


Figure 113

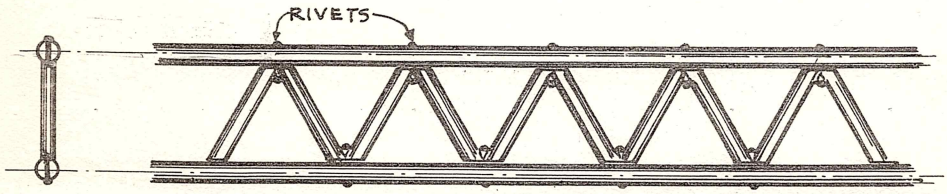


Figure 114

In Figure 115 a heavy spar section is shown. A spar of this nature is extremely heavy and strong, unless light gauges are used. It utilizes a riveted half round section connected by a lightened shear member. The lightening cut-outs are flanged.

The Vickers-Wibault spar is shown in Figure 116. The member is merely two channel flanges with a corrugated web member riveted top and bottom through flanges. The various modifications are also indicated. This spar is very efficient for cantilever or braced structures, and economical to construct.

The spar shown in Figure 117 is another form of the steel tubing flange spar. The shear members are dural tubing arranged in a Warren truss with pin fastened through the flanges on the side of the top and bottom members.

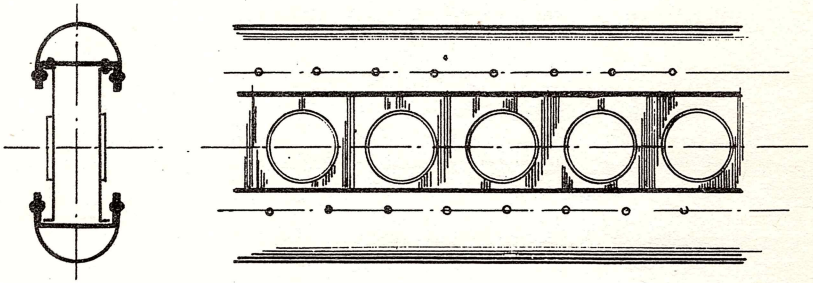


Figure 115

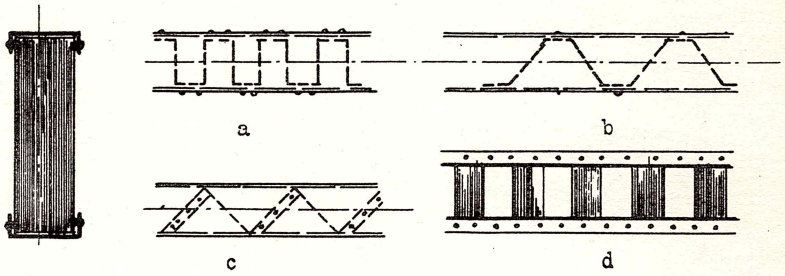


Figure 116

VICKERS - WIBAULT

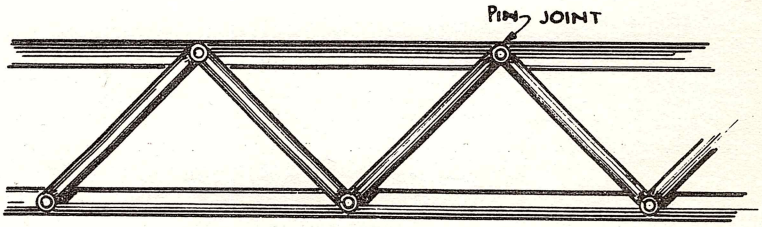


Figure 117

The welded spar of steel tubing has been widely used from time to time. Spars similar to this are used in the Stinson Airliner and the Curtiss Condor of earlier type. The spar has proven satisfactory in service although somewhat heavy and difficult to weld. This spar is indicated in Figure 118.

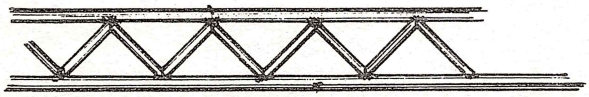


Figure 118

FRONT SPAR STINSON HIGH WING
TRI-MOTORED AIRLINER

The Fairey Aircraft spar is widely used in England, Belgium, and Greece, by the Fairey interests. It is an excellent spar and stiffened by channel members riveted to the web. This spar is used also as a compression strut. Figure 119.

Figure 120 is merely the standard "I" beam spar with no auxiliary stiffeners. Merely shown for comparison.

Figure 121 is an experimental wing spar. Spars of this type may be used as drag members in the drag truss. The spar is a modified box and very efficient.

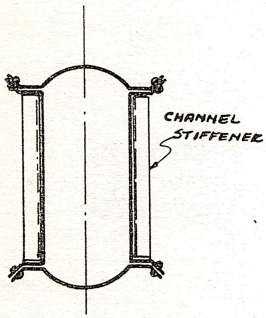


Figure 119

Figure 120

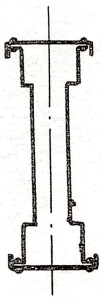


Figure 121

Figure 122 is another experimental modification similar to the Fairey. Stiffener channels on the web may or may not be used, depending on the web gauges.

Figure 123 is a modified box spar. The web is lightened and also held together between the circular cut-outs by means of a spacer sleeve with a pin jointed rivet spun over as the spacing tie.

The Bristol spar is indicated in Figure 124. This spar, when properly braced in the truss, is extremely light. The circular cut-outs are flanged, and the spar is built of steel.

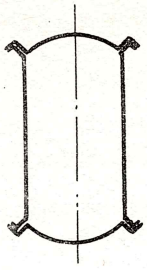


Figure 122

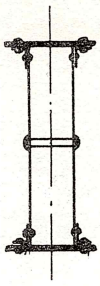


Figure 123

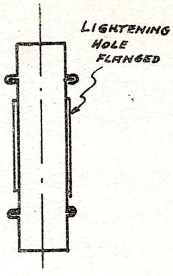


Figure 124

Figure 125

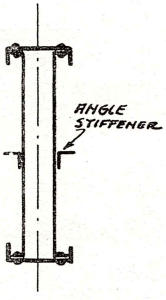


Figure 126

Figure 127

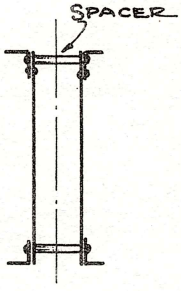


Figure 128

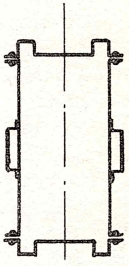


Figure 129

BOULTON & PAUL

The rolled spar riveted together is shown in Figure 125. Spars of this type are built of light gauge steel and rolled or braked to shape.

The box spar shown in Figure 126 is further strengthened by a system of diagonal angle stiffeners running along the web and riveted thereto.

The channel type of spar shown in Figure 127 is a simple production spar, and is adaptable to tapered wing construction with a minimum of cost. The web may be riveted to the main channel and be of alloy or steel, as desired.

The open box spar is shown in Figure 128. This spar is merely used for light loads. The webs are held apart by sleeves and pin jointed rivets. This member can be used for a drag member.

The Boulton and Paul is an all steel formed and rolled box spar, and has proven extremely efficient. The side webs are further stiffened by a system of diagonal channel stiffeners riveted to the shear members. The spar is shown in Figure 129.

The rolled tubular steel spar with an open throat riveted to the lightened and grooved web is popular in Europe. Spars of this sort are extremely light when properly braced. See Figure 130.

The Junkers wing spar, as exemplified in Figure 131, is utilized to success in the Junkers Junior Sport airplane. The spar is simply an al-

loy dural tube with a corrugated web member with the rivets running through the sides of the top and the bottom tubular flange members. This spar is extremely light and has proven to be ideal in light metal aircraft.

The spar shown in Figure 132 is merely the open channel type with riveted channel members comprising the web and shear members. The members are riveted direct to the spar flanges.

The structural type of spar, similar to steel truss sectors, has found wide use in aeronautic work. The section is fabricated of two heavy gauge flat pieces top and bottom with angles riveted thereto. The web members are merely angles riveted to the flanges and held by gusset plates. Spars of this type have found considerable use. Refer to Figure 133.

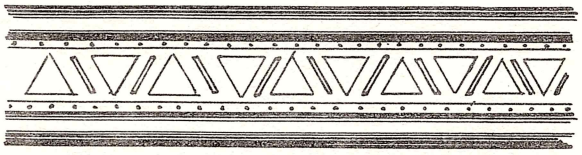
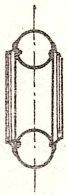


Figure 130



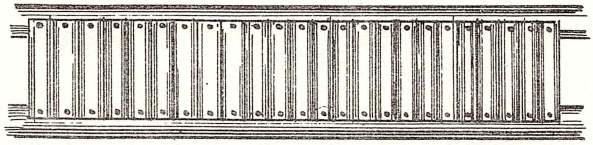
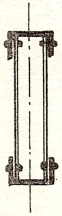


Figure 131

JUNKERS SPORT PLANE



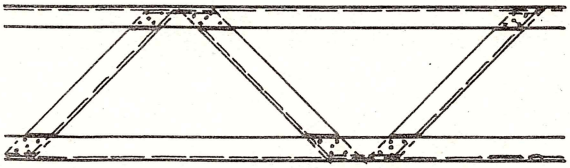
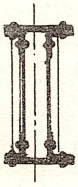


Figure 132



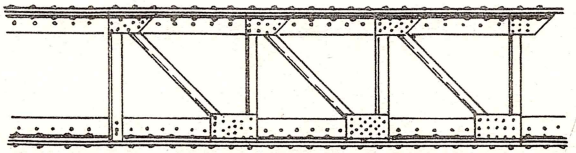


Figure 133

The Ford Trimotor utilizes the truss type of spar shown in Figure 134. This spar is extremely strong in the tapered construction. It has a half section tubular flange top and bottom with angle web members riveted to heavy gusset plates. The spar can be constructed economically with a minimum of cost and the strength to weight ratio is extremely high.

The tubular flanged spar is shown again in Figure 135. This spar is merely two steel tubes connected by a web member with circular cut-outs and riveted through the sides of the top and bottom tubes.

The spar shown in Figure 136 is a built-up spar of two heavily pressed thick gauge flanges. The shear members are riveted to the flanges and are of the channel section. This spar has proven quite satisfactory.

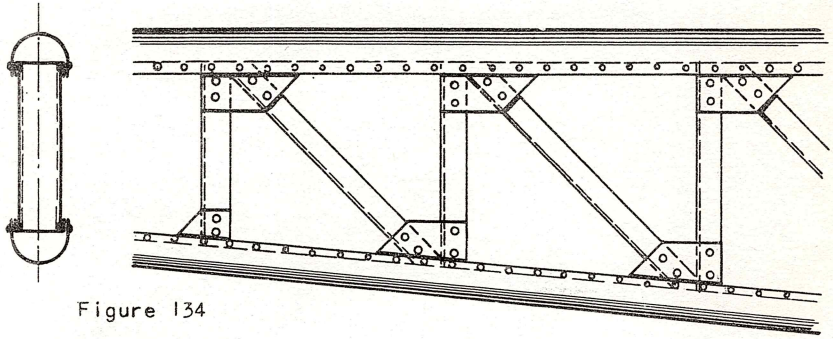


Figure 134

FORD - STOUT

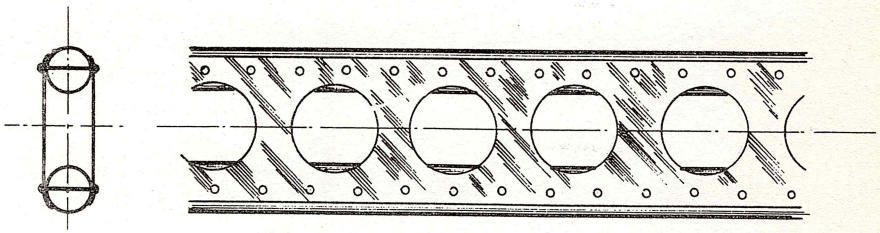


Figure 135

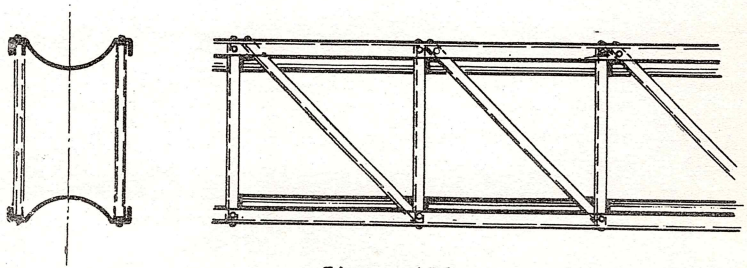


Figure 136

The open form of channel flanges is shown in Figure 137. This spar is simply two inverted channels connected by a circular cut-out web member and suitable stiffening channels at specific intervals. The spar is built of dural alloy.

The Dornier spar, used in some of their smaller transport planes, is shown in Figure 138. The Dornier spar is composed of two inter-connected and riveted formed dural alloy channels. The lighter channel and the heavier channel have lightening circular cut-outs with the spars riveted together at the top and bottom through the side flanges of the spars. This requires inside riveting. The form of channel spars of this type, while very efficient, is a job to accomplish with most leaf types of power brakes, since the clearance for the brake has to be accounted for. To do the operation and to clear the brake, one flange is formed; and then the other is gradually formed by spreading the two formed flanges apart to clear the brake. The spar is then straightened.

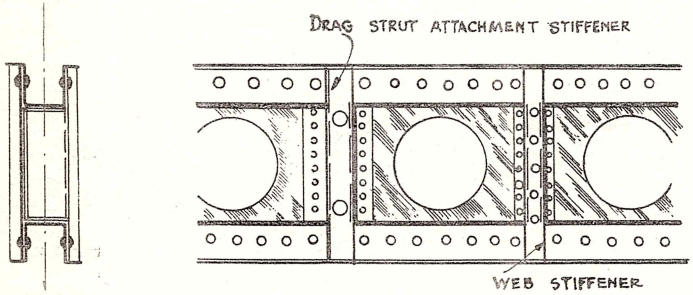


Figure 137

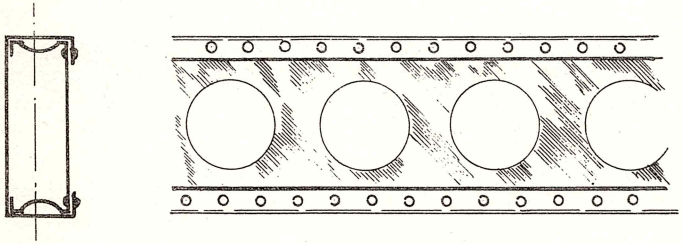


Figure 138

DORNIER

The Douglas Company has developed the spar shown in Figure 139. This spar is a modification of the usual tubular flanged type and possesses several distinct advantages. It can be all riveted on the outside, and the hexagonal flange members are easily formed. The web is a corrugated member riveted through a flange to the hexagonal sections. This spar is very efficient and economical to build.

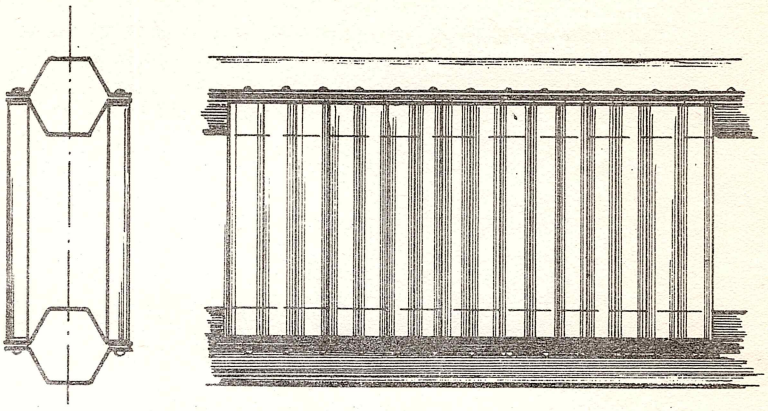


Figure 139

DOUGLAS

The spar in Figure 140 is an experimental spar with a triangular lightened web reinforced with diagonal channel sections. The flange members are heavy gauge channels with smaller angles underside riveted to the flange. This spar requires auxiliary bracing in torsion and drag forces.

The Armstrong-Whitworth sections, developed for use in the "Atlanta" transport plane for Imperial Airways, are shown in Figure 141. These sections are formed of dural alloy and are very economical to build. They are very efficient in service and the weight to the strength is high. They are utilized for a number of purposes, especially as spars and beams.

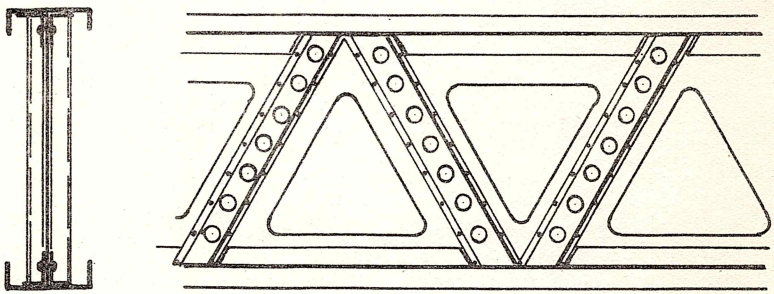


Figure 140

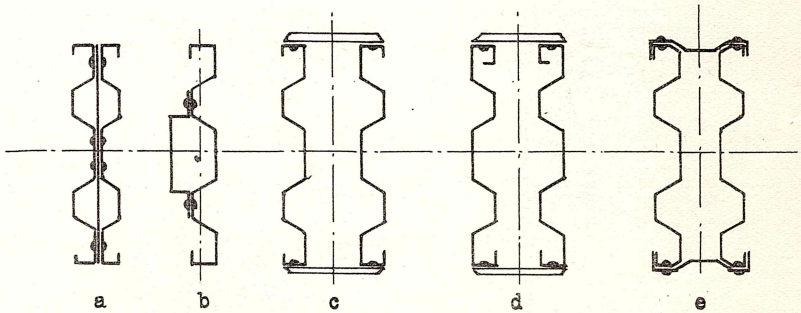


Figure 141

ARMSTRONG - WHITWORTH

The mono-spar wing has proven to be quite practical using the Steiger type of truss. The Steiger Truss uses one spar to carry all the wing loads. This spar must be very stiff in torsion since the wires carrying the rest of the wing loads, and on which the stiffness of the wing depends, are all anchored to the spar flanges. See Figure 142.

The spar is composed of a very heavy flange member with two-side angle braces and a top formed section to give further resistance to bending. The web material is very thick to prevent failure by torsional forces.

Boulton and Paul have developed the spar shown in Figure 143. This spar is built up of steel and is a modified "I" beam with a lightened web member further braced with riveted stiffeners.

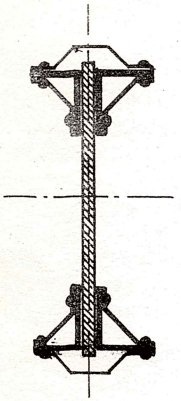


Figure 142

STEIGER

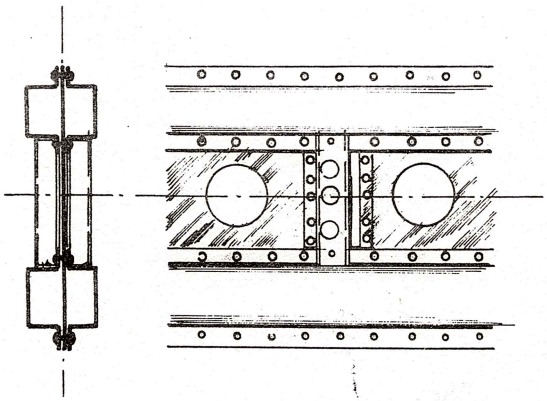


Figure 143

BOULTON & PAUL

The spar shown in Figure 144 is a light dural spar with an open channel top and bottom as the flanges. The web is lightened with circular cut-outs. This spar must be braced against torsion since it is unstiffened.

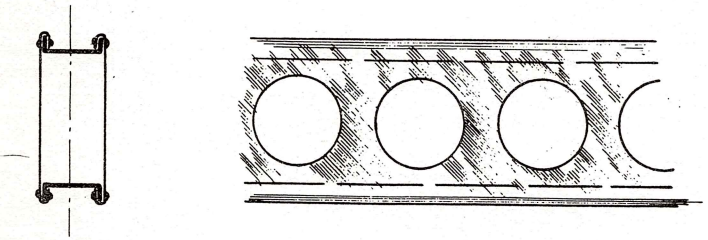


Figure 144

The spar shown in Figure 145 is of the single web variety. The web is light gauge dural with triangular lightening holes and channel side stiffeners diagonally arranged. The flange members are special rolled steel shapes.

The Bristol Company has patented the spar section illustrated in Figure 146. This spar section is very attractive since the production problems are simple.

The Grumman Company uses a spar similar to the one depicted in Figure 147. The flanges are heavy dural channels with an alternated web section of medium gauge thickness. The members are staggered on each side alternately and riveted to the flanges. The cost of this spar is comparatively low with the more complicated fabricated types. The strength factor of this spar to its weight is extremely high since it is an elemental box section, the lightest and strongest for strength to weight. This spar is an excellent example of metal design.

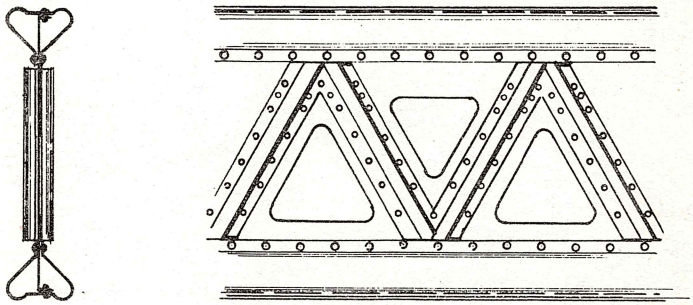


Figure 145

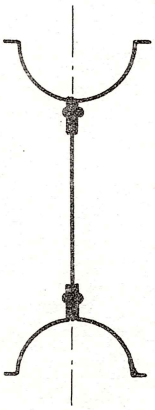


Figure 146

BRISTOL

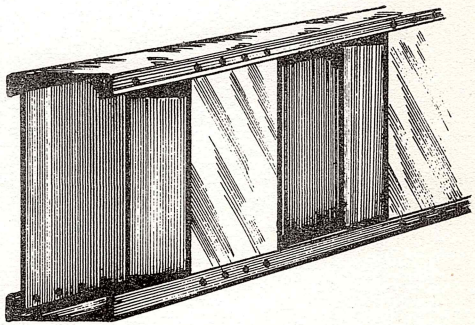


Figure 147

GRUMMAN

Figure 148 shows the truss type of cantilever spar built up of rolled heavy strip sections.

Figure 149 shows another modification of a strip type of spar with a Warren truss web system. The members are further stiffened by grooving the same.

Figures 150 to 152 are examples of light gauge rolled steel wing spars. These spars are merely modifications of the basic box section, and have proven to be extremely strong to the weight. The spars are ideal for thin wing biplanes.

The spar in Figure 152 is a special rolled construction, using a corrugated rolled thin gauge wall and the spacing achieved by a sleeve member with spun-over ends. This spar is suitable for biplane wings.

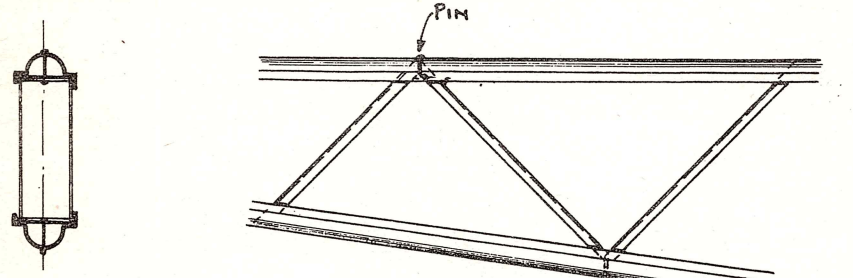


Figure 148

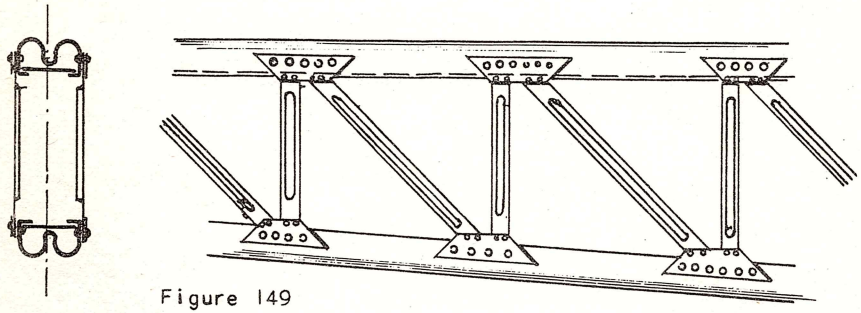


Figure 149

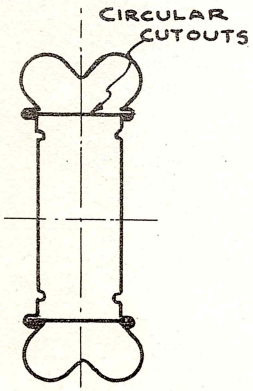


Figure 150

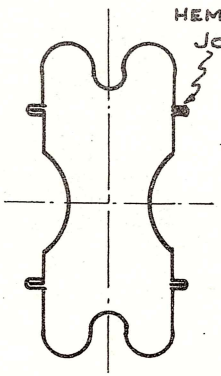


Figure 151

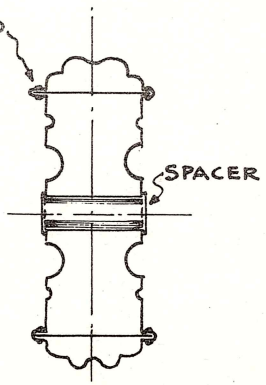


Figure 152

Figure 153 is another example of a box type rolled, light gauge, steel spar.

Figure 154 is a spar developed by the Fairey Company, being rectangular, solid, seamless tubing slightly deformed to secure additional strength by rolling the same to the shape.

Figure 155 is another example of a light box spar. The web in this instance is the heavier gauge with the channels being merely spacers. The spar is of dural.

Figure 156 shows a spar using rolled flanges with a single web of solid material of heavy gauge.

Figure 157 is a special steel box section perfected by Boulton and Paul of high strength, light gauge, steel. It is built with steel spacing sleeves and lightening holes in the web.

The Armstrong-Whitworth spar is depicted in Figure 158. The web is of light gauge steel with stiffener channels. The spars are polygon sections built and formed in three pieces, and all riveted together.

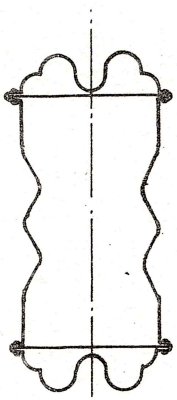


Figure 153

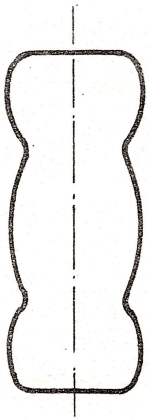


Figure 154

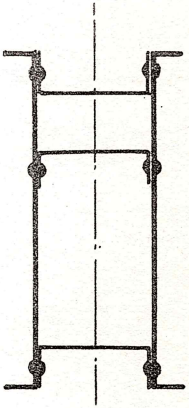


Figure 155

Figure 156

FAIREY

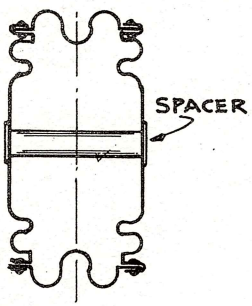


Figure 157

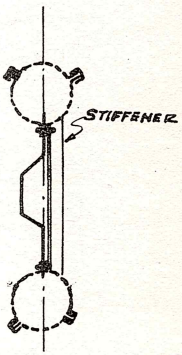


Figure 158

ARMSTRONG - WHITWORTH

Figure 159 to Figure 162 show a group of special spars experimentally developed, using the rolled steel strip method and riveting construction. These spars are modifications of the "I" and the box sections.

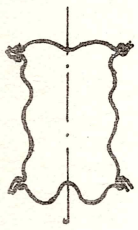


Figure 159

Figure 160

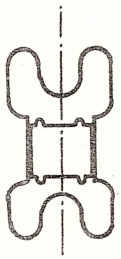


Figure 161

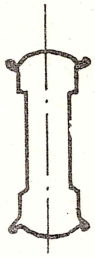


Figure 162

Figures 163 to 165 show other modifications of rolled, light gauge, steel box and tubular sections developed experimentally.

Figure 166 is a special form of "I" beam modification with heavy gauge rolled dural flange members top and bottom with webs lightened and stiffened.

Figure 167 is another form of the "I" beam spar using a diagonal system of shear trussing in the web all riveted to the vee section flanges.

Figure 168 is an experimental box spar with multiple layer flanges developed by Handley Page.

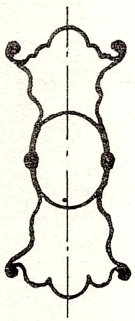


Figure 163

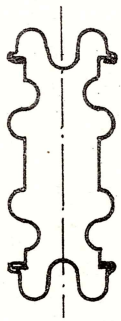


Figure 164

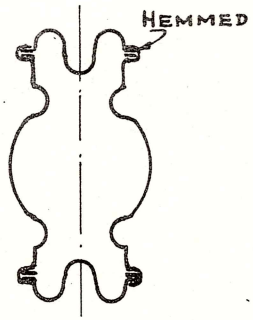


Figure 165

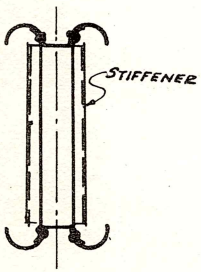


Figure 166

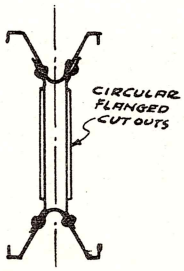


Figure 167

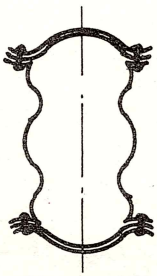


Figure 168

Figure 169 is another modification of the "I" beam with a light gauge high tensile steel being the material utilized. Beams of this sort must be braced against torsion, and are suitable for biplane wings.

Figure 170 is another example of the tubular type of spar, using tubular spar members with a lightened web with flanged holes.

Figure 171 is another form of box spar built-up and riveted, using light gauge steel of high strength. This is suitable for biplane construction in light gauges.

Figure 169

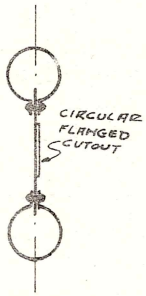


Figure 170

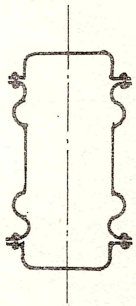


Figure 171

Figure 172 shows another version of the plate type of girder spar with a lightened web and stiffeners at specific intervals riveted to the web. Note the flanges are flat bulb members with angle clip members riveted thereto.

Figure 173 is another version of the box spar, using a heavy rolled flange member with special rolled web members riveted thereto. The web is lightened and stiffened by wide channel stiffeners riveted to the web.

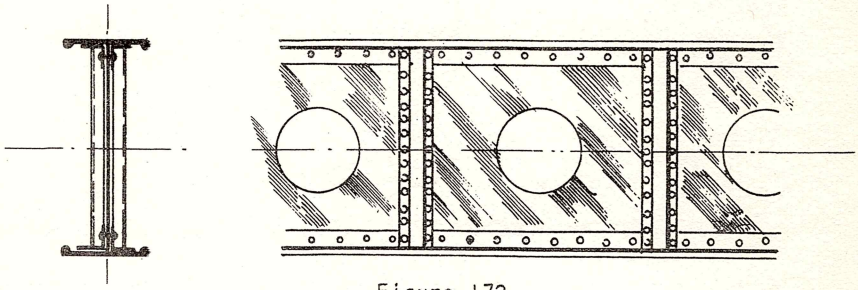


Figure 172

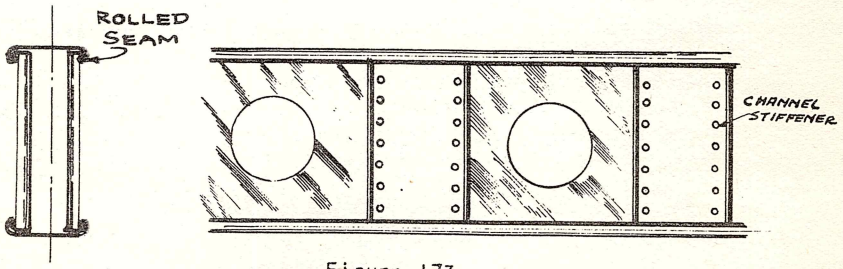


Figure 173

The modification of the "I" beam is again illustrated in Figure 174. The flanges are special rolled members with a lightened web and diagonal channel stiffeners.

Two experimental rolled spar shapes are shown in Figures 175 and 177. They are made of light gauge high tensile steel and rolled.

The spar in Figure 176 shows the end section of a spar with an open channel of hexagonal half shape. The shear members are simply a Warren truss system of channel members diagonally arranged with riffled lightening holes. The whole affair is built of dural.

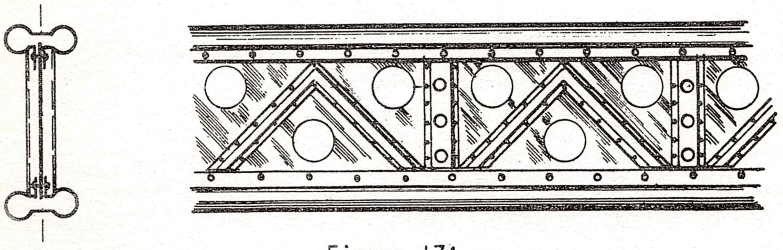


Figure 174

Figure 175

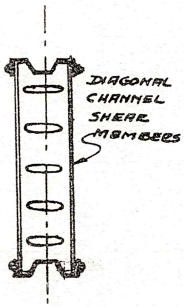


Figure 176

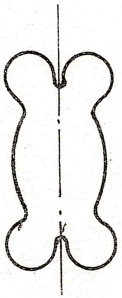


Figure 177

Figure 178 is another example of a rolled steel spar. This shape is adaptable to braced wing construction.

The tubular spar flange has been utilized in many ways. As shown in Figure 179 the tubular throat is separated by a channel member and to this is riveted the tubular flange and the diagonal shear members. The shear members are grooved dural or steel with the flange members being the same.

The experimental triangular spar is shown in Figure 180. No examples of this have seen extensive service, it being shown merely for comparison. The flanges are corrugated dural riveted to the dural flange members with an open throat. This spar requires inside riveting, since the webs are solid.

Figure 181 is another example of the modified box spar with light gauges. Three longitudinal members with riffled lightening holes at specific intervals and three hemmed seams comprise the construction.

The Hawker spar, shown in Figure 182, is a very efficient section, and has found wide application in Hawker service aircraft. The spar is composed of two hexagonal flange members and a channel formed web with a channel vertical stiffener at specific intervals.

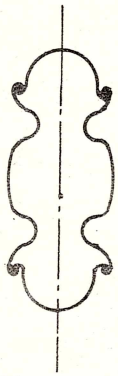


Figure 178

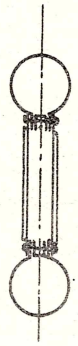


Figure 179

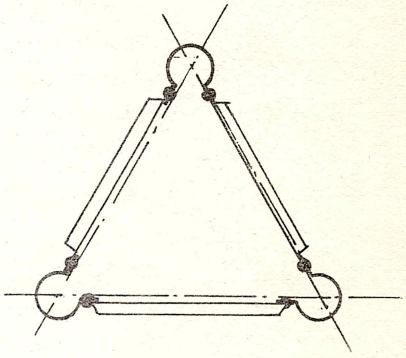


Figure 180

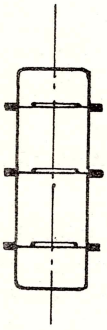


Figure 181

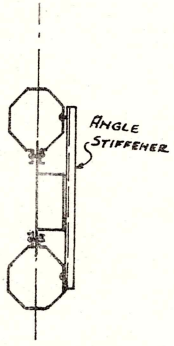


Figure 182

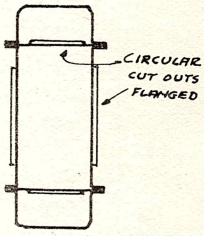


Figure 183

HAWKER

The spar shown in Figure 184 is another modification of the "I" beam. The web is of moderate gauge with triangular cut-outs and channel stiffeners riveted thereto at specific intervals.

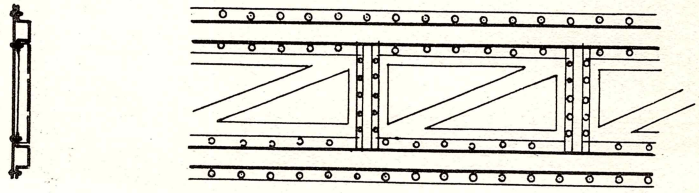


Figure 184

Figures 185 and 186 show examples of rolled, high tensile steel, wing spars with tubular flanges riveted to the webs, which have been formed into various shapes.

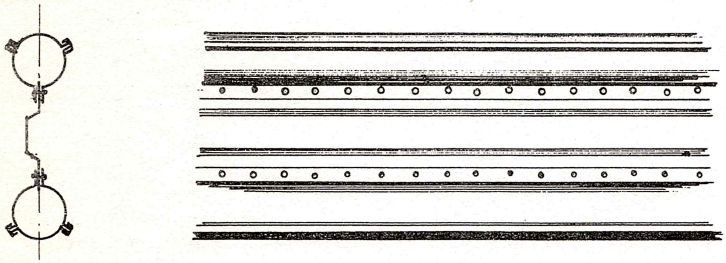


Figure 185

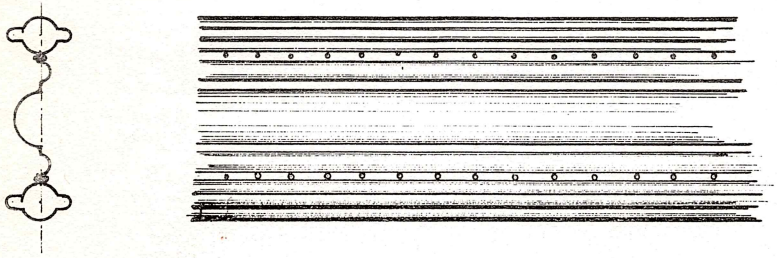


Figure 186

Figures 187, 188, 189, 190, 193, depict special spars built up of rolled sections of light gauge steel. These spars are further adaptions of the box section.

Figure 191 shows the circular spar. This spar is composed of four sectors of the circular shape which, in reality, comprise a 24-sided polygon. The seams are riveted and covered with a light channel member.

Figure 192 is a section of the steel "boom" utilized in the Breguet fighting aircraft. The actual boom is built with somewhat wider width than illustrated.

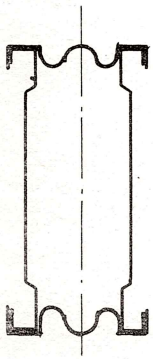


Figure 187

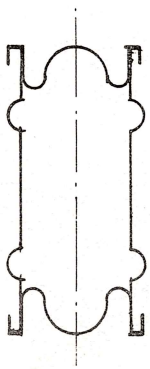


Figure 188

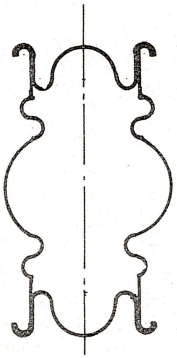


Figure 189

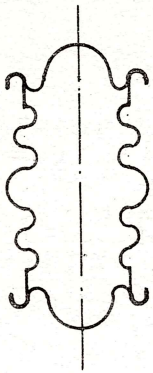


Figure 190

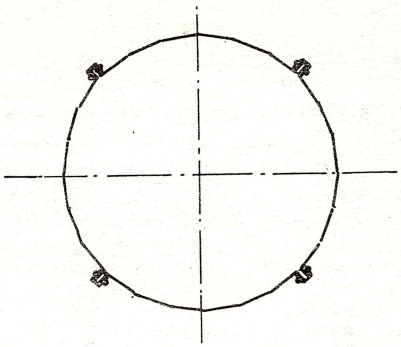


Figure 191

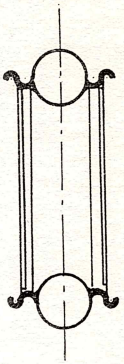


Figure 192

BREGUET

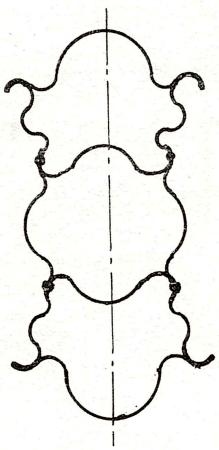


Figure 193

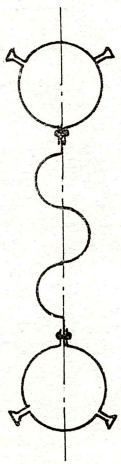


Figure 194

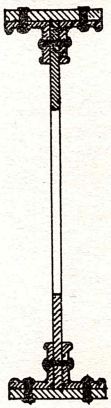


Figure 195

The rolled section shown in Figure 194 is a fabricated and rolled spar of high tensile steel. Spars such as this possess remarkable strength when properly braced.

The plate girder is an example of certain beams utilized in aircraft float construction. Note the bulb angles. Figure 195 shows the heavy web member lightened.

The built-up girder shown in Figure 196 is the Blackburn used in large dimension aircraft. This is merely orthodox practice, being a typical built-up girder of flat and angle section with a web trussing arrangement braced by small diagonal angles.

Figure 197 is an example of the open throated channel spar with a lightened web, channel stiffeners, and gusset plates riveted thereto.

Figure 198 shows a special rolled flanged spar. The flanges are of special high strength steel, and the web is lightened and grooved with triangular cut-outs.

The Supermarine flying boat spars are shown in Figure 199. This is merely a deformed channel with suitable stiffeners at specific intervals. The web is solid. This spar is very strong, though somewhat heavy.

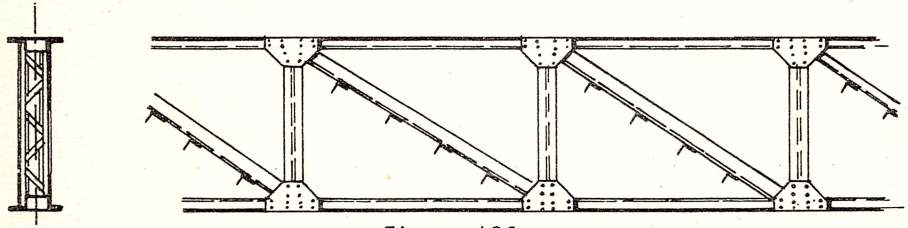


Figure 196

BLACKBURN

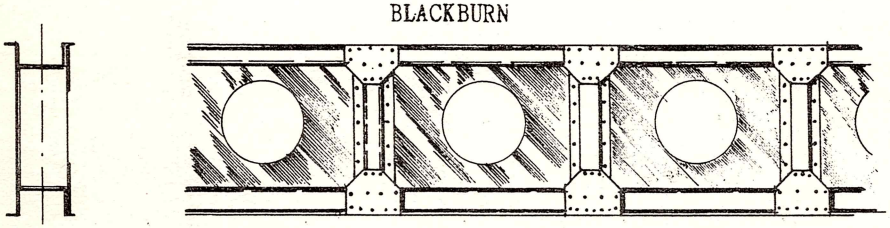


Figure 197

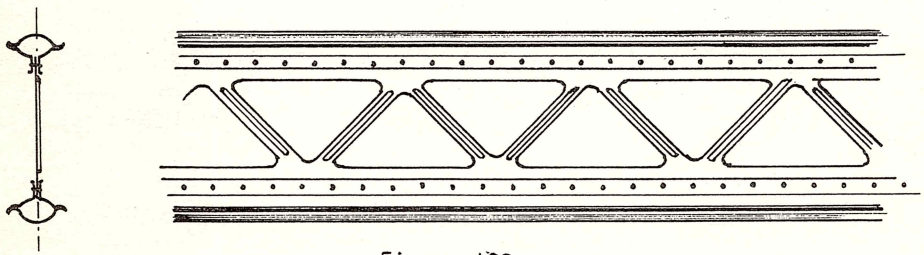


Figure 198

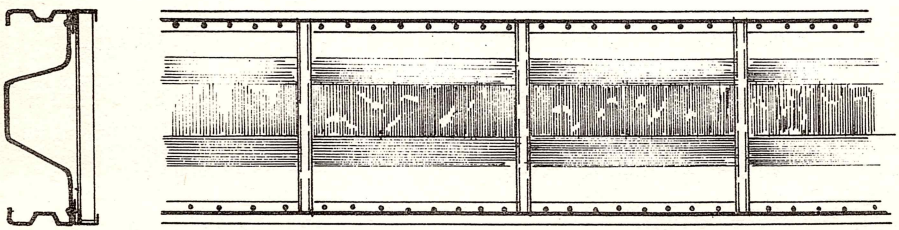


Figure 199 SUPERMARINE

The rolled section is entirely experimental and shows what a diversity of radii are possible with rolling. Figure 200 illustrates typical current practice for rolled strip, high tensile steel, spars.

The plate type of girder in Figure 201 is merely an "I" beam of the orthodox structural shape. The web has large circular cut-outs strengthened at specific intervals with angle members riveted to the flanges.

The "I" beam shown in Figure 202 is merely an adaptation to aircraft design of the structural type of plate girder. The web is solid and stiffened by angle pieces riveted to the web at equal intervals.

Figure 203 illustrates the plate girder construction used in the Rohrbach flying boats. The web is unstiffened and has triangular cut-outs, as shown. In this structure the skin of the wing carries some of the load.

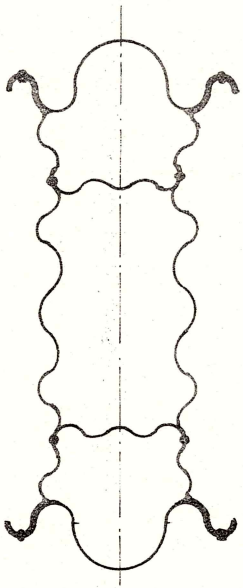


Figure 200

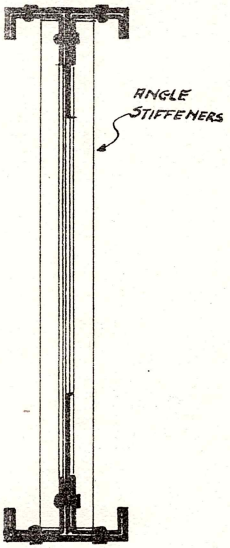


Figure 201

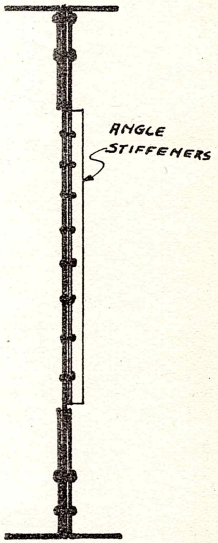


Figure 202

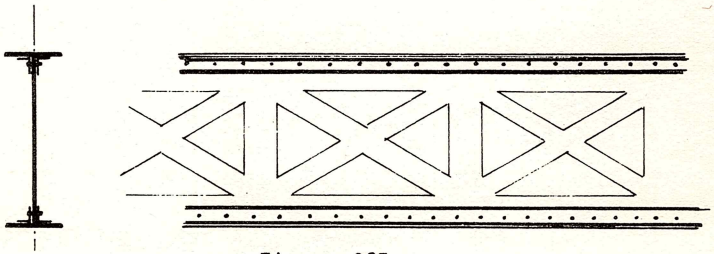


Figure 203

ROHRBACH

The Rohrbach box girder is shown in Figure 204. This girder has heavy channel flanges and light gauge webs stiffened with riveted tee shape stiffeners.

The Dewoitine dural cantilever spar is used in the long distance monoplane built by that concern. The spar is the open lattice work type with vertical web channels and diagonally cut-out web members stiffened and riveted. The spar is shown in Figure 205.

Figure 206 depicts a spar similar to that used by the Martin Company in the long range seaplane, using a cantilever wing. This spar is very light with a larger upper flange than a lower flange. The spar is stiffened by vertical channels riveted to the web.

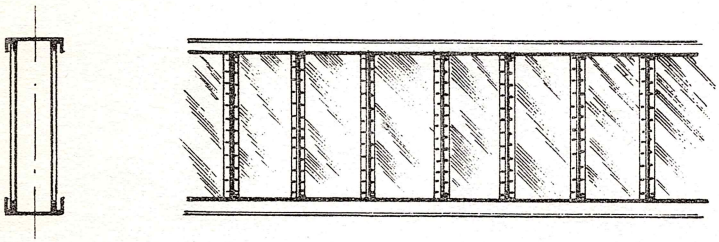


Figure 204

ROHRBACH

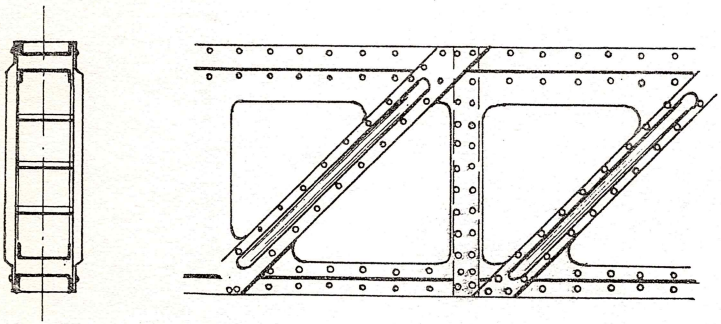


Figure 205

DEWOITINE

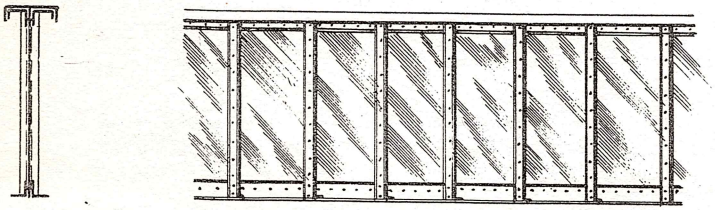


Figure 206

MARTIN

The Amiot spar is one of the earliest used in the French metal aircraft. The spar is simply rolled dural tubular flanges riveted together. Where the drag members occur the cut-out is made smaller. The spar is extremely light. This spar is shown in Figure 207.

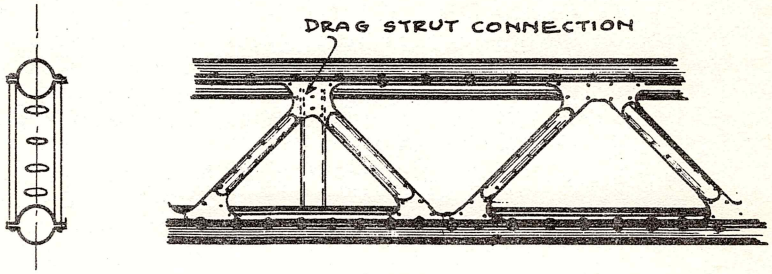


Figure 207

AMIOT

The Supermarine Racing Seaplane utilizes the spar shown in Figure 208. The top and bottom flanges are of heavy gauge material with the webs of lighter gauge formed as drawn. The formed web stiffening curvature is cut out at specific intervals so that the spar may be built to allow the wing ribs to pass through the same by a system of cut-outs. The webs of the wing ribs are of solid sheet alloy and fit snug up to the web of the spar by means of angle clips and riveting. This type of wing construction, when metal covered, makes a very rigid surface.

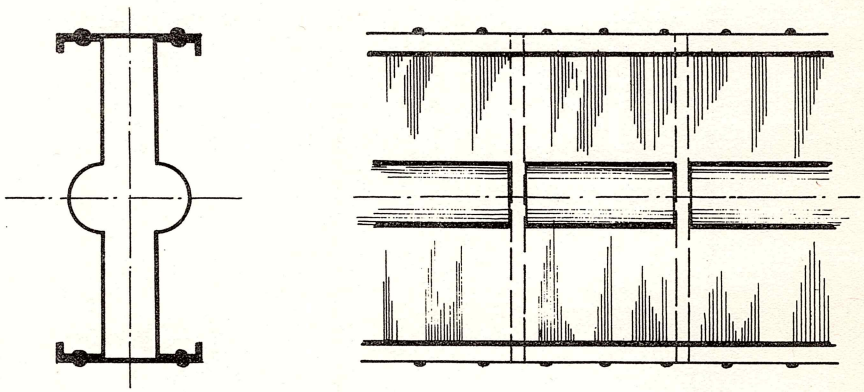


Figure 208

SUPERMARINE

An example of the use of laminated light sheet metal strips to reinforce the metal wing spars in critical conditions is shown in Figures 209 and 210. The first illustrates the method used by the Bristol Company to reinforce the web of a metal spar. The web is solid.

To stiffen the spar against lateral bending another layer of formed strip is riveted on the inner flanges at the top and the bottom. This method increases the strength very greatly. The use of laminated sheets is lighter construction than if correspondingly heavier pieces of material were used. The outer pieces must fit snugly and smoothly when riveted, and show no bulges or crinkles.

In Figure 210 is another example of using high tensile strip steel in a wing spar. This spar is of Russian design, and is built up by the method of shot welding. The spar is shot welded together at close intervals. This shot welding process is light in weight and has the same strength in steel as shear riveting.

To further stiffen this spar and to increase its depth another piece at the top and bottom is shot welded on to the main spar. The weight to strength ratio of this spar is very high and it is strong in bending and torsion.

Spot welded dural spars have been extensively employed in France. In Figure 211 is an example of a spar built for the AMIOT concern by this method. The spot welding of dural is being developed to a point where it is a serious contender to riveting, because it is much faster and lighter in weight.

The secret of good spot welding of dural lies in the short current time the metal is subjected to the electricity. The welding by the spot process takes place above the critical temperature of the material. It has the same strength as riveting when completed.

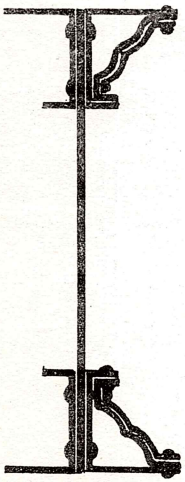


Figure 209

BRISTOL

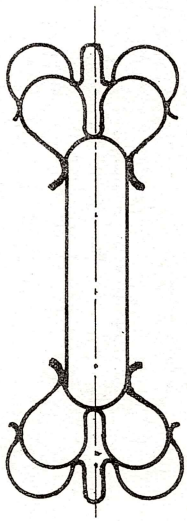


Figure 210

RUSSIAN

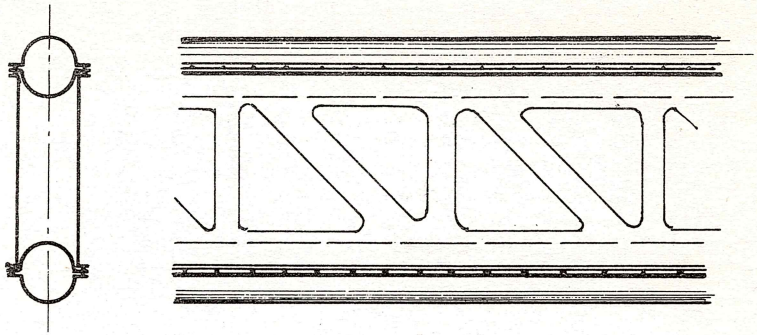


Figure 211

AMIOT SPOT WELDED SPAR

The process uses high localized heating of the material to be welded. The parts are squeezed together under pressure and then slightly parted. The two pieces to be joined are then welded by application of the current, and then squeezed. Aluminum requires extremely high current because of its high conductivity.

The circular spar section shown in Figure 212 is a development of the Blackburn Company in England. This spar is very light in weight for its strength. It is more efficient than a corresponding I beam of equal weight. The material is concentrated very efficiently. The top of the beam is reinforced by a double layer of corrugated skin riveted to the shell structure. The spar itself is built up of metal of light gauge, all riveted together. The spar is tapered. The center of it, where the diameter permits, is made water tight and used for a fuel tank.

The spar shown in Figure 213 is developed from steel strips and riveted together. The shear members are of the ordinary diagonal trussing pattern held together with gusset plates.

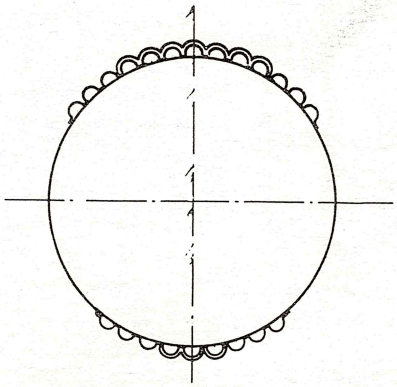


Figure 212

BLACKBURN

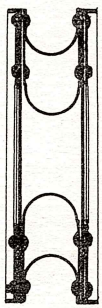


Figure 213

CZECHO-SLOVAKIAN

The section shown in Figure 214 is an example of a cylindrical tube. This tube is formed of two parts with the joints made by seaming and squeezing down. The spar is made of light gauge high tensile steel, and produced in a variety of shapes for various uses.

The use of shot welding has been pushed extensively in the construction of Russian aircraft. The material used is high tensile light gauge steel. The process used is licensed under the Budd patents. The material is rolled to shape and then shot welded. Two typical sections from Russian aircraft are shown in Figures 215 and 216 and show what may be accomplished by shot welding. Each section is made in various sizes and gauges for whatever strength is required.

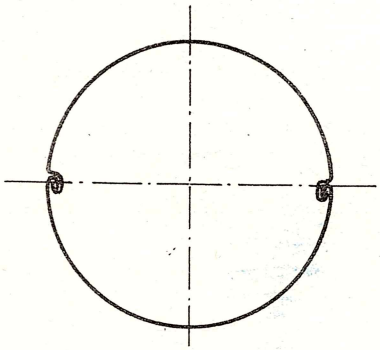


Figure 214

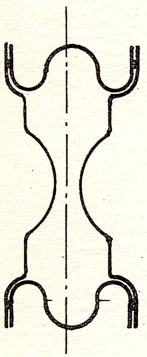
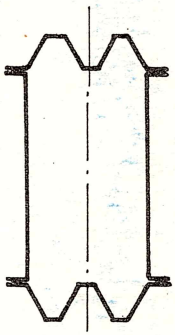


Figure 215

RUSSIAN SHOT WELDED MEMBERS



ANY OF THE CLOSED TYPE OF SPARS MAY BE USED AS A COMPRESSION STRUT IN A WIRE BRACED WING TRUSS IN 2 SPAR WINGS. OPEN SECTIONS ARE NOT AS EFFICIENT AS A CLOSED SECTION. THE CLOSED SPAR SHAPES CAN BE USED AS CONTROL SURFACE SPARS AS WELL. FOR ALL GENERAL STRUCTURAL PURPOSES THE BOX TYPE SPAR IS SUITABLE.

Figure 216

CHAPTER VII

METAL TAIL AREAS

There are many forms of metal tail areas. Metal tail areas are desirable for many reasons other than aerodynamic. The tail area is one part of the plane that does receive much wear from rocks kicked up by the slip stream, tall grass, ruts, and likewise, handling.

The metal tail area in either all metal of the stressed skin type, or all metal covered of the frame type, or the all metal frame fabric covered, is widely used in construction. The stressed skin type has the advantage of lightness and extreme strength. The cost is the greatest of any form. The frame type metal covered ranks next to the ideal of stressed skin areas, and has been widely used,particularly in military planes where metal control areas are required for fireproof reasons encountered in combat and also for strength.

The welded steel type fabric covered has been the standard for cheapness and light commercial construction in the U.S.A.for many years, and was originated by Fokker in Germany during the war. The cheap cost offsets its lesser durability. The efficiency of the areas is about the same in any form as far as aerodynamic reactions go. However, the cost, being the dominating feature, has fostered the development of structures using dural ribs, wooden spars,and fabric covering for a composite structure.

Tail areas, unless they are cantilever, are more or less modifications of wing airfoils.Some are simply flat plates,and the aspect ratios vary from three to six. The aspect ratio is important because of structural reasons; hence this accounts for short squatty surfaces, when perhaps the larger aspect ratios would be more efficient aerodynamically, but more costly from a production standpoint.

The use of all metal surfaces in any form is the ideal to be approached. The stressed skin type, while costly, has the better of the many advantages and is widely coming into use. The best examples of this are the Douglas and the Northrop.

For serviceability the tail areas should be built so they can be easily replaced. This wear is caused by handling and landing hazards; hence quick replacement is essentially an important feature. Metal tail areas should have a relatively stiff and heavy gauge nosing to preclude the denting of the surface by rocks thrown by the propeller in landing and taking off. In fact, this deforming of the surface makes way for corrosion and pitting unless protected. A good idea is to paint any surface exposed to the slipstream rock particles with a bitumastic or rubberized paint, or even a thin coating of sheet rubber, cemented to the area affected. This precludes rock dents and pitting.

ALL METAL TAIL AREAS

The Martin YB fin is illustrated in Figure 217 and the same method of construction is utilized.The fin skin is stiffened by outside string-

er members over the smooth skin. The internal structure is of dural framework alloy.

A tentative diagram in Figure 218 depicts the Douglas DC-2 fin area. The construction is an internal frame of dural covered with a smooth riveted skin.

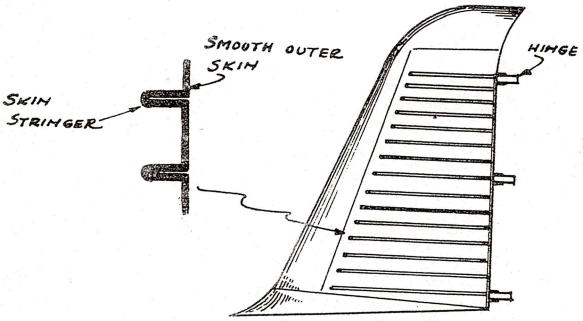


Figure 217

MARTIN YB BOMBER FIN AREA

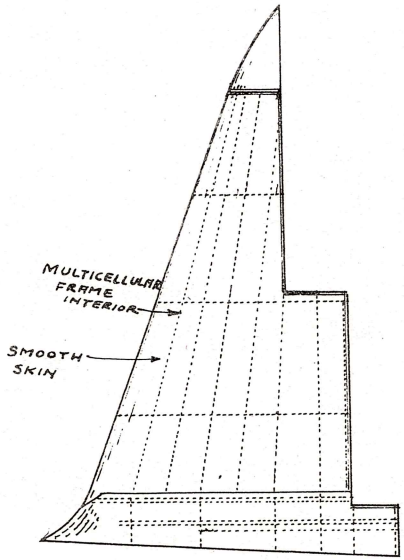


Figure 218

DOUGLAS DC-2 FIN

Figure 219 illustrates the method of covering the tail areas on the P-12E. These forms of surfaces depend on an internal structure with the outer corrugated skin riveted to the same. These areas are very strong and durable.

The Northrop horizontal tail area is shown in Figure 220 and the method of shell plating. The internal structure is similar to the Northrop metal multicellular wing. These surfaces are very durable.

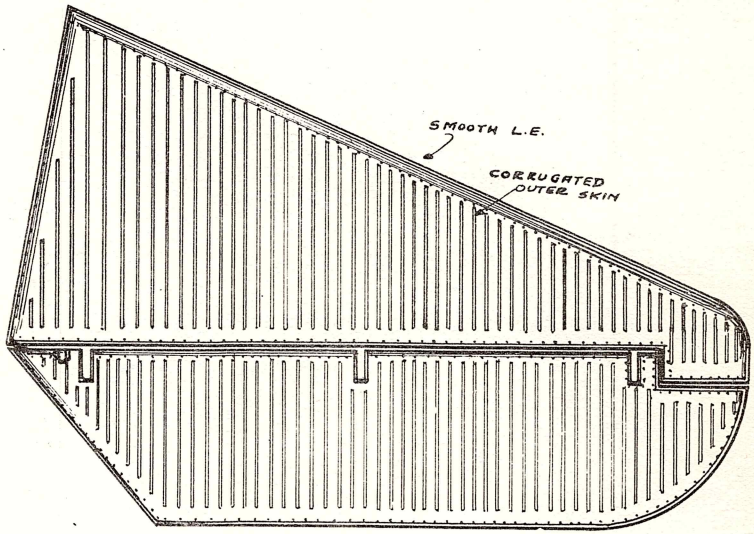


Figure 219

BOEING P-12 ELEVATOR
AND STABILIZER AREA

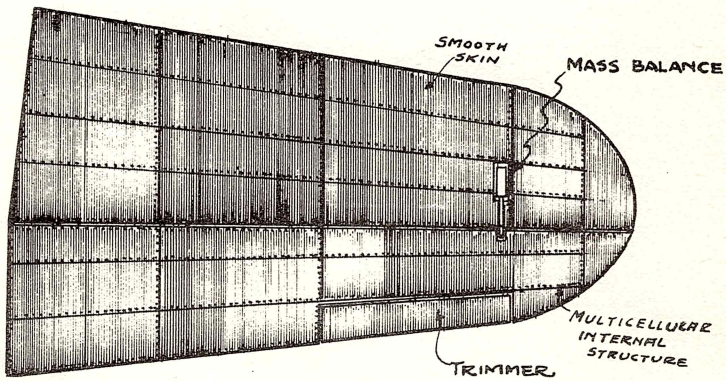


Figure 220

NORTHROP STABILIZER & ELEVATOR

The vertical areas of the Consolidated Fleetster are shown in Figure 221, and illustrate the method of constructing a leading edge of circular pattern which, in any case, is difficult and requires forming. This type of construction ingeniously obviates the usual difficulties for a surface of this sort. The rudder is stiffened by a formed corrugated skin.

The Curtiss Fighter F9C-2 utilizes a riveted framework of dural covered with smooth sheet for the tail areas -- both vertical and horizontal. The Figure shows the covering removed. The horizontal areas are similarly built. See Figure 222.

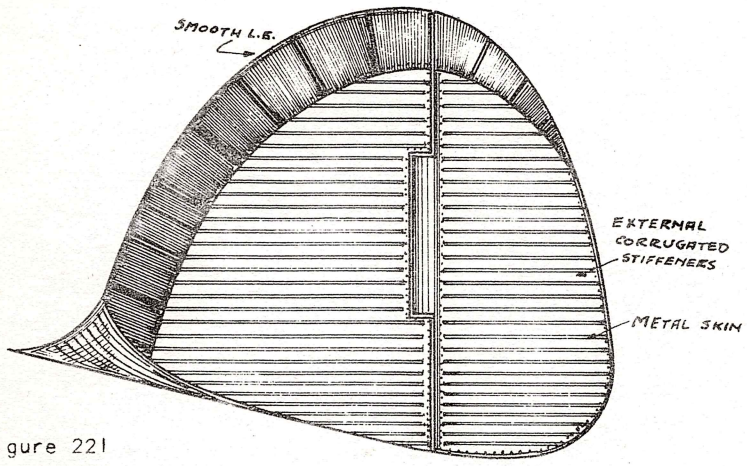


Figure 221

CONSOLIDATED FLEETSTER
Rudder Detail

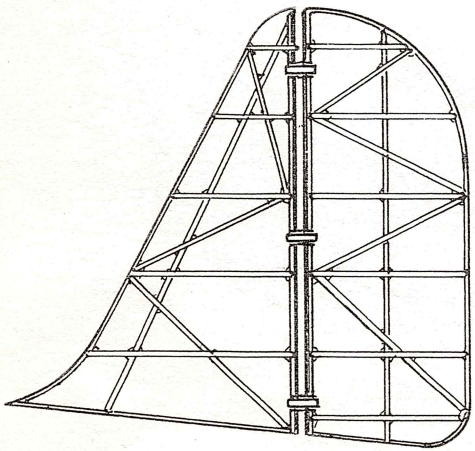


Figure 222

CURTISS F9c-2
Vertical Tail Areas

METAL FRAME TAIL AREAS

The Sikorsky horizontal tail areas are shown in Figure 223 for the tail of an amphibian produced by this concern. This is a splendid example of dural frame elevator construction and the stabilizer as well. This structure is covered with fabric and has proven durable.

The rudder of the Curtiss O-1 observation aircraft for the U. S. Army Air Corps is another example of metal frame rudder area covered with fabric. See Figure 224.

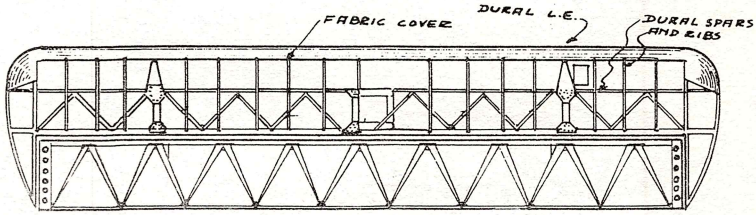


Figure 223

SIKORSKY
Elevator and Stabilizer
Riveted Frame Structure

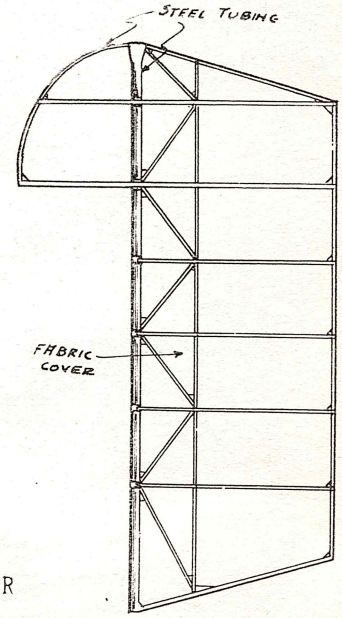


Figure 224

CURTISS O-1 RUDDER

The rudder of the Curtiss PW-8A is shown in Figure 225. This is the usual method of framework utilizing steel tubing welded together and then covered with doped fabric. This construction is light and very strong. The fabric is doped and laced to the frame work.

The tail areas of the Curtiss PW-8A for the U. S. Army Air Corps is shown in Figure 226 and illustrates the method of trussing. This type of surface has found extended use in commercial and military aircraft. The fabric is laced and doped over the framework. The main structure is of light gauge steel tubing with the auxiliary bracing members welded thereto as well as the hinges and the actuating control members.

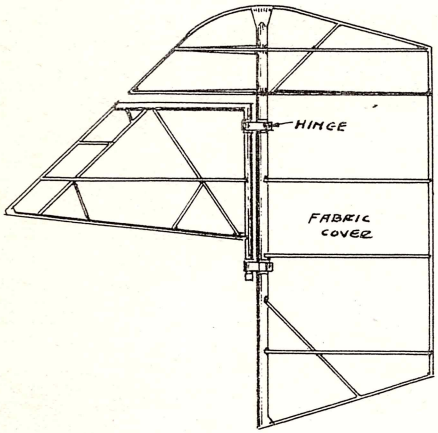


Figure 225

WELDED STEEL VERTICAL TAIL AREA ASSEMBLY CURTISS PW-8A

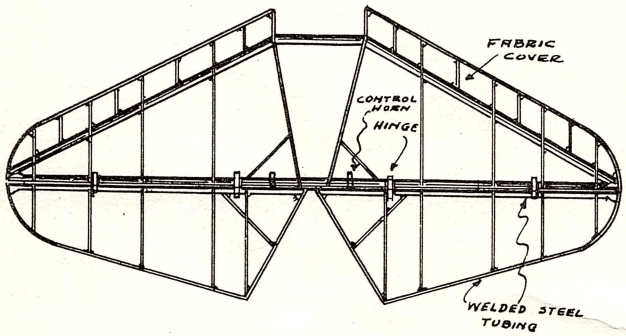


Figure 226

CURTISS PW-8
Stabilizer and Elevator

CHAPTER VIII

MISCELLANEOUS METAL PARTS

The number of metal parts that go to make up the average airplane is numerous. The small part production is deserving of study since these miniature parts make up a vast total of the gross weight of the fuselage when taken collectively. Anything saved in weight, without sacrifice of strength, is something gained.

Small parts are made up by various methods in the metal aircraft. The fittings, if of steel, are always produced from a flat pattern on the nibbler machine and then formed up in some sort of die press or brake. Holes are drilled after forming to avoid stretching. Metal parts of dural alloy of small size are either of the soft alloy or heat treated where strength is required. All in all the production of miscellaneous metal parts of small and large nature runs into a considerable part of the production cost and time for the modern metal aircraft.

LONGERONS

Longerons are the long metal members running longitudinally the length of the fuselage. A longeron may be an extruded section, produced in a brake, or manufactured on the draw bench. Whatever method is used depends on the material and the shape. As a general rule the longer the longeron stock lengths the better, since the ideal condition allows that no joints be used (if at all possible) for a maximum of strength. Longerons are produced in a variety of shapes, the most common being the "T", "J", channel shape, the angle, or the "U" section.

FAIRINGS AND FILLETS

Fairings of one sort or another are merely non-structural contours used primarily to reduce the drag by improving the flow of the boundary layer of the airplane. Fairings are metal parts of flat stock formed into the desired shape by use of hand bumping tools or the power hammer.

The fillet is used at the junction of the wing root and the fuselage. A fillet is merely a special form of fairing. The fillet is formed much the same way as the ordinary fairing except it has a specific curvature and radius throughout its length, and it may possibly reflex at the trailing edges. Fillets, if of large size and radius, are built up in many parts of sheet stock and stiffened on the inside. The production of the fillet is a highly specialized piece of coppersmithing.

BULKHEADS

Bulkheads can be built in numerous ways and means. The cost of bulkheads depends on the type and the method of fabricating. Bulkheads for the same weight of material have the same strength if the metal is disposed correctly. For large bulkhead construction, the metal is best produced in flat patterns, and then formed up and joined by splice

plates. This is the most economical method and produces the bulkhead with the most strength for least cost in material and labor. At the present time formed bulkheads by means of pressing are limited by the cost, although ideal in theory.

Any bulkhead must be so designed that the minimum of waste may be realized. Waste in any form in dural represents high cost in material. Hand forming of bulkheads is not used in commercial production since "U" shapes, or other shapes produced in this manner, are extremely difficult to produce continually the same. Hand working, on the other hand, also alters the structure of the metal to a hardness where further workability is not easily accomplished; hence this is limited to small production of experimental planes. As a matter of fact all parts are, whenever possible, worked by machine in preference to hand working, since the uniformity achieved is a matter of great importance and does so with a minimum of spoiled parts.

COWLS

The almost exclusive use of the radial engine necessitates cowls of special pattern for the engine drag reduction. These cowls are so constructed that they must necessarily be a mild form of structural element, because they are subject to considerable handling on the ground.

Engine cowls are large sheet metal parts that are produced on rolls, and then the nosing is formed either by hand or on the power hammer. The cowl is stiffened on the inside with circular stiffeners of channel section, and also has fittings riveted to the outer shell for attachment to the engine or the fuselage.

Engine cowls are further stiffened by a heavy ring member around the opening of the throat of hollow section. The edges and the edge of the skirt are stiffened by either hemming over a hollow dural tubing edge, or just a plain hemmed edge stiffened by flat members at intervals. Cowls should be so constructed when being built that they may be sectional for engine inspection and easily removable for servicing. Engine cowls are usually built of 20 gauge material for the larger sizes and 22 to 24 for the smaller engines.

In the matter of securing the same, the fittings must be substantial since any vibration of the engine will fatigue the fittings, rapidly causing a failure that may cause a forced landing by the cowl working loose.

Ordinary cowling for "in-line" engines is a modification of that used in current automotive practice. Engine cowls of this kind are equipped with louvres if using a liquid cooled engine, and with scoops or louvres, or both, if using "in-line" air cooled engines. The cowls of this kind must be heavy construction and reinforced on the edges. The material should not be less than 20 gauge to stand handling and stiffened by flat or channel members on the inside. Cowls are fastened by screw and snap members, or else wired into place through small stud members on the fuselage. The edges should all be hemmed and wired for durability. If the cowl is subject to much wear the material should be of the moderate hardness dural alloy and preformed for the contour. Soft dural in a cowl deteriorates very quickly under vibration and handling, and consequently cracks and fails thereby requiring renewal.

SHEET STOCK

In the effort to reduce production cost the necessity for designing and developing parts that will not require special sheet sizes or large sizes with big wastage is much to be desired. The various sheet sizes of dural have been established by the Aluminum Company, and every effort should be made to produce parts that will work out with a minimum of wastage.

For a multiplicity of parts, which are manufactured from flat stock, patterns should be made and these laid on the sheet and so arranged that a maximum of patterns and blanks can be cut from one sheet. In this way waste is cut to the minimum.

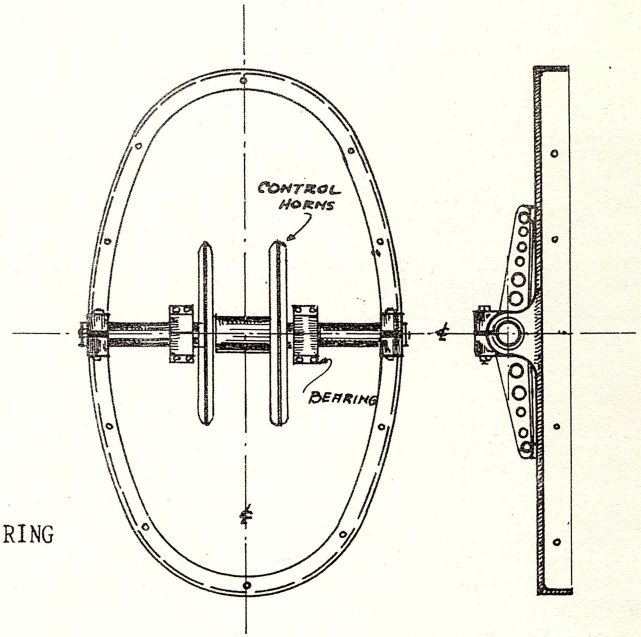


Figure 227

CAST DURAL EMPENNAGE RING

The above is an example of a part that is produced by casting. The casting is the cheapest method of producing a part like this on a production basis, since every part is uniform and the strength is high with a minimum of weight. The difficulty of small radius working on sheet stock of channel or angle shape is immediately apparent; hence the use of a casting in a case like this is advisable. Castings may be used for numerous other parts and their wide use is justified.

Castings like this are always cast with allowance for shrinkage. After machining and drilling they may be heat treated to a higher degree of strength as well. Electron Metal and Lautal as well as magnesium are all possible to cast up for the various parts required if the right technique is pursued and a freedom from flaws achieved.

JUNKERS WING ROOT FITTINGS

A very fine example of good spar fitting is found in the Junker wing. This type of fitting was perfected during the late war. The fitting is made in two types, one of which is adjustable for dihedral. The fitting itself is of dural, machined with large cut threads and locked in place with steel screw nuts and fittings. Steel and aluminum do not freeze or bind in threading, which makes detaching easy. Figures 228 and 229.

The inside of the fitting is further reinforced by a steel liner inside riveted to the walls of the spar tubular member. The efficiency of fittings of this sort may be attested to since they are still in use today on Junkers aircraft and have not failed in service. This form of fitting allows rapid detachment of the wings. These are shown in Figures 228 and 229.

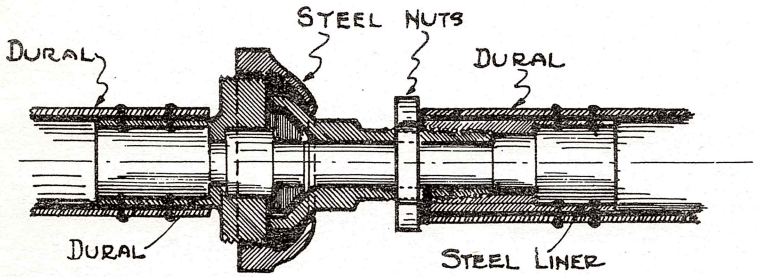


Figure 228

JUNKERS NON-ADJUSTABLE SPAR JOINT

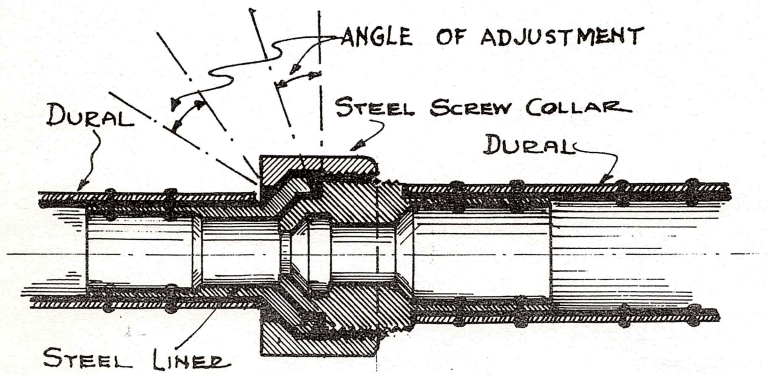


Figure 229

JUNKERS ADJUSTABLE SPAR JOINT FOR
VARIOUS DIHEDRAL ANGLE SETTINGS

METAL BUCKET SEATS

Bucket seats are always a necessity of some sort for every aircraft. The bucket seat is the lightest and the strongest, and is produced by hand forming or power hammering. The edges are rounded over light gauge tubing. Soft dural is used for the seats. The average bare seat weighs about 6 to 8 pounds. The seats are held by riveted fittings to the fuselage for safety. The bottom is either bucketed for a cushion or seat pack parachute, as desired, and the back made with circular cut-outs for lightness.

INSTRUMENT BOARDS

Instrument boards are made of soft dural and machined, and cut-out for instruments. The companies supplying instruments often supply the boards when all one make of instruments are used, and in this way do a very good job. The instruments are imbedded in sponge rubber for safety to the pilot in event of a crash. Instrument boards should be insulated against vibration by imbedding the mountings in a sponge rubber fitting.

FLOORING

Flooring has to carry the load of the cabin or the freight. For lightness, it is of corrugated section laid in long sheets and of medium hardness, unless heavy loads and rough usage is the order of things. On top of the corrugations, which are stiffened structurally and anchored to the fuselage, a light plywood or linoleum floor is used in passenger planes, whereas corrugated floor and walls are used in freight and mail planes. The floor must be strong enough to afford staunch anchoring for the chairs and fittings for the same.

MISCELLANEOUS METAL FIXTURES

These include the various items on passenger planes, such as the lavatory fixtures, the wash room fixtures, the ventilation system and the ducts and fixtures pertaining thereto, and the dining equipment -- if any. While all these seem trivial, yet each requires a specialized treatment in design to suit the requirements of light weight, compactness, cost and cubic displacement.

Fixtures of this sort may, at times, be purchased from companies other than the firm building the plane. A list of the weights of equipment of this sort is found in the weight section. In this list may be included, as well, the radio equipment, landing light system, material for the retracting mechanism, and the shock absorbers on the landing gear.

In the effort to secure the best in each line specialization of equipment has led to the purchasing of many of these parts as accessories made by firms specializing in the equipment. However these parts require many clips, angles, brackets, ties, etc., for their installation, and production of these is made by the aircraft concern.

CONTROLS

Controls cover a multitude of items. The controls are always built

of metal and require a number of special machined parts and fittings. The control list includes throttles, braking pedals, rudder pedals, bell cranks, bearing members, brackets, fittings, torque tubes, cables, actuating arms, and hinges. Each item is a specialty in the design of itself. Included in controls may be the fire extinguishing system, the flare releases, landing lights, mechanism for the retracting gear, and the indicators for all of these things.

METAL FUEL TANKS

The fuel tank has always been a source of difficulty in the search for the ideal type. The tanks are made from a number of various materials, ranging from terne plate to sheet brass. At the present time the duralumin shell tank is relegating the use of the other materials into the background.

Fuel tanks must be securely and strongly built. A tank that weighs a few pounds more and stands up under service conditions is better than a lighter one that is a source of trouble and leaks. Any type of tank for fuel and oil must have joints that will stand vibration and surges of the contents induced by flight accelerations. A good tank should be able to stand five pounds pressure per square inch without appreciable distortion. The larger the tank the less the weight in proportion to the amount of fuel it may contain.

Dural is the ideal material for tank purposes. The seams may be soldered or welded and riveted, or a combination of the three. The thickness of the wall material may run from 18 gauge up to 14 gauge, depending on the internal structure and the baffle plates, and what degree of strength they contribute to the shell. Tanks may also be braced by means of internal stay bolts as indicated in Figure 230, which shows the detail of the attachment to the tank wall.

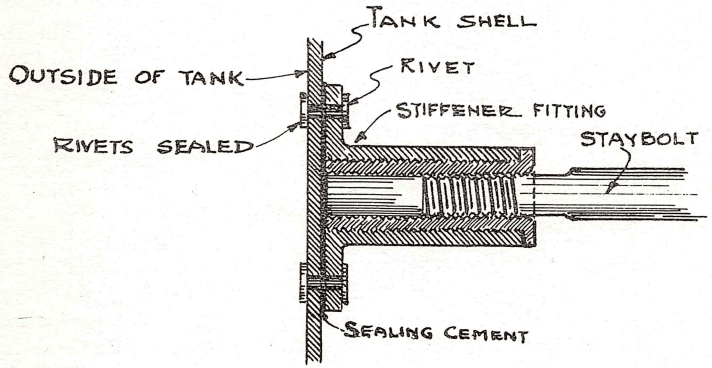


Figure 230

DETAIL OF STAY BOLT REINFORCING

For a maximum of strength the flat shaped tank should not be used except when absolutely necessary. Tanks of this shape do not provide the maximum of strength, and are subject to failure from handling very quickly. The tank in any shape or form must be provided with stiffening members both on the inside and the outside. The baffle plates should be so disposed on the inside that they contribute some of the strength of the tank as well as prevent surges of the liquid. The sides of large fuel tanks should be both stiffened and corrugated as well, since this increases the strength. The internal baffle plates should be so perforated that in all positions of flight the tank can drain without hindrance.

Fuel tanks can be built of welded aluminum or any of the alloys if the gauge is sufficient to do a good tight seaming job without chance for leakage. The seam should be beaded on a large radius, and the weld puddled and formed so as to seal the joint effectively. Any outlets to any of the tanks if welded around should be reinforced. A suitable tank filler neck flange is shown in Figure 231. Note that this type permits the tank to stand the loads imposed by fuel hoses without damage to the tank walls. Most tanks are in inconvenient positions if built in the wing. Fuel hoses are quite heavy and are generally supported by the filler neck flange while fueling. This imposes a strain on the shell of the tank with a chance for wear and leakage. The filler neck for rapid servicing should be of large size -- preferably over 3" in diameter.

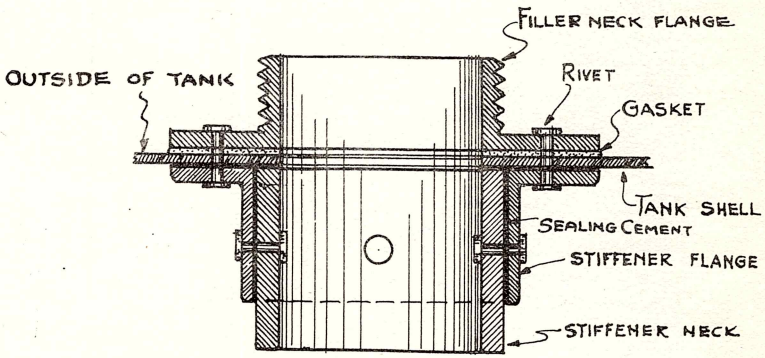


Figure 231

DETAIL OF FILLER NECK

In Figure 232 there is shown a typical large capacity fuel tank. This tank is reinforced on the outside by corrugated walls and by outside straps fastened to the side walls by riveting. The straps have rolled edges for additional strength, and the baffles are riveted to the side walls as well and prevent crushing of the tank side walls.

Riveting of fuel tanks have found some application. The joints are all packed up with a sealing compound or with annealed aluminum. Riveting, however, is further improved by soldering or welding.

The installation of fuel tanks is always a problem. At present most tanks are held in the fuselage by means of straps of metal with a turnbuckle adjustment. In this way they may be removed or tightened into place. These straps should be built of light gauge steel strap material and should be fastened to suitable lugs that are riveted to the tanks to assure tight installation.

In Europe fuel tanks have been made of various materials. However, to gain lightness without the recourse to heavy structures in large planes, the tanks are built up over a structure similar to the skeleton

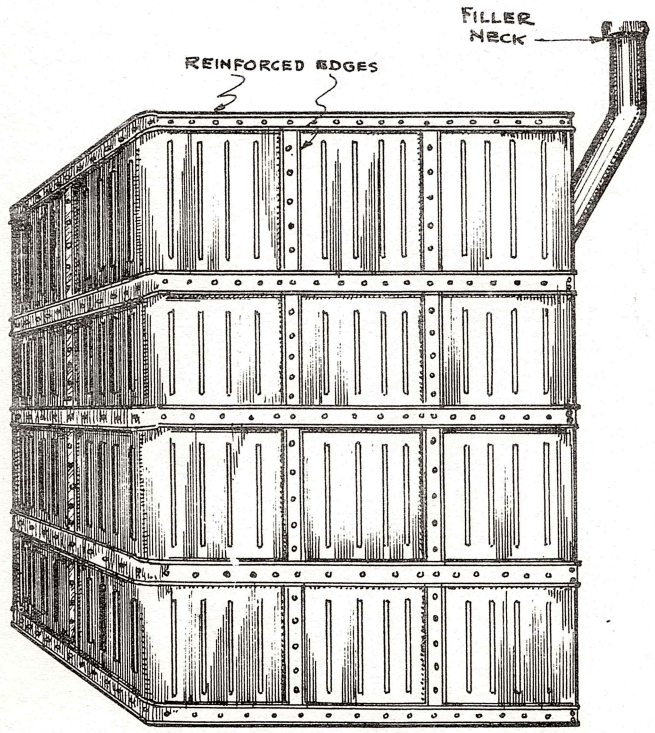


Figure 232

METAL FUSELAGE FUEL TANK

of the monocoque frame of a shell structure. This produces a good strong tank although more costly than the ordinary shell tank with internal braces. A monocoque tank of this sort will stand hard use. The baffles are merely thin gauge material and contribute but little strength. Welding and riveting seem to be the choice of tank fabrication in Europe.

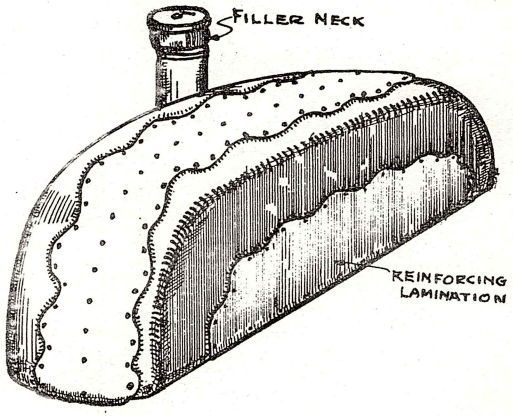


Figure 233

METAL OIL TANK WELDED AND RIVETED CONSTRUCTION

For lightness oil tanks are built up of soft dural and welded or riveted for tightness. Since oil tanks must dissipate heat, the heat conductivity of the tank shell aids in cooling the oil as well. The tanks are built up of light gauge dural -- preferably 20 gauge. The outside of the tank may be reinforced by external pieces of the pattern shown, welded and riveted to the outside to lend stiffness to the structure. A tank such as this is merely a metal shell with a few non-structural baffles on the inside.

The filler spout projects out of the rear from a filler flange welded to the tank walls after the walls have been reinforced either by added welded and riveted laminations or otherwise. The oil tanks are subject to surging forces created by accelerations in flight as well as expansion due to the heat of the oil and the normal oil forces while it is in circulation. The tank must also be provided with a strong exterior so that it may stand servicing, handling and also mounting.

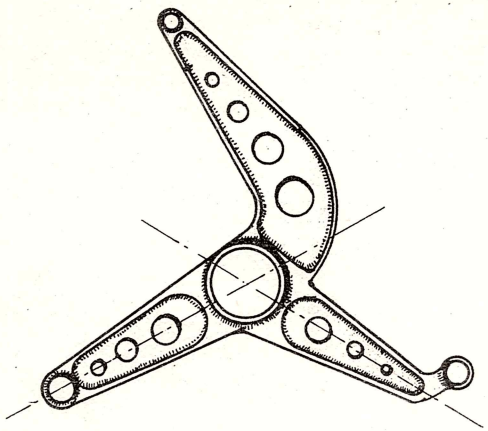


Figure 234

AN EXAMPLE OF A DURAL CASTING AILERON BELL CRANK ARM

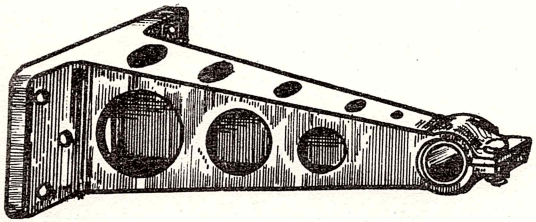


Figure 235

AN EXAMPLE OF DURAL CASTING AILERON SUPPORTING BRACKET WITH BEARING BUSHING

CHAPTER IX

SERVICING

The servicing of all metal shell structures is a problem for the mechanic as well as the airplane designer. Methods and design have not progressed far enough to a point where the economy in servicing and spare parts have been cut to the irreducible minimum. The methods so far developed have been modifications of the servicing requirements of composite structures. As the use of metal aircraft construction becomes greater, servicing will be reduced to an economical minimum, at present impossible.

Until comparatively recently, the only requirement of a specific design was that it could fly. Such designs rapidly proved that they were uneconomical in air line operation. Designs such as these were immediately washed out, once the air lines endeavored to make a profit. The salary cost of the ground crew, the lack of forethought for part replacement, and the time required for each operation brought home the fact that successful air line operation was dependent on the servicing operations to a very great extent.

The servicing problem was immediately tackled by the airplane engineer. In a gradual process of evolution, the servicing problems have become simplified. The result is that an air line now can operate with a much greater reduction in the fixed charges for servicing than could have been done several years previous.

The clever aeronautical engineer must not merely be a good designer. First, he should be a good pilot. Second, he should be familiar with the overhaul and the methods used in ground servicing. Third, he should be a competent and practical designer in using his knowledge to enable the owner of the airplane to keep that machine in service the longest time for the least outlay. Unless the airplane designer can understand the pilot's requirements, the mechanical problems of servicing, and the owner's financial and operating requirements he'd best devote his energies to something less complex. Until recent years practically every airplane for commercial use was designed with the idea for payload only. As the air line business expanded it was at once apparent that payload and revenue were not the only considerations. Some thought must be devoted to keeping that plane in operation constantly. Thus, by natural sequence, the problem of servicing has grown to be perhaps the most vital one in the fixed charges of air line operation. In this, metal shell structures have decided advantages.

One of the main reasons for the all-metal airplane structure is its uniformity of parts made possible through quantity production. Another sound reason for its existence is the permanence and long life of the all-metal plane. With these two advantages combined into one structure, the soundness of the investment in all-metal plane structures is possible to understand even though the initial investment is higher at the start.

COSTS

Costs in any form detract from the income of an air line. If they be high, the profit is small. Under the exigencies of competition profits must be sufficient to maintain the organization and the requirements of operation.

For example, two planes each with the same performance and cost are offered for sale to the prospective air line concern. If one was built of wood and the other of metal, the decision would be to purchase the metal plane. The reason is that the permanence and minimum deterioration would be less on the all-metal aircraft. The fact is obvious. If the servicing or maintenance of each was according to the merits of its particular construction, the edge would lie in favor of the metal plane. Therefore, under the requirements of competition, metal aircraft are the logical answer to low operating cost. Operation and maintenance charges must be the deciding factor. They accrue over the years of the life of the plane. The initial cost is of secondary importance under such circumstances.

Quantity production is very easily accomplished with metal structures. Each part can be made uniform with a minimum of final cost and outlay. These parts are very easy to replace for old and worn out parts. Whether metal, wooden, or composite structures, every part is subject to deterioration. The question to consider is how long is the life. The labor cost is affected by the time for part replacement. If the part to be replaced takes an excess of time, the design is inefficient from low cost requirements. As in most phases of airplane design a compromise must be made in many items for the sake of low maintenance outlay.

INTERCHANGEABILITY

The airplane is a structure which is massed around a center line. The fuselage must be symmetrical about this line. Each wing and every item of the whole plane's surfaces, therefore, are classed as right or left. In ordinary design this means that double the amount of spares must be carried over that for a design that is not subject to "handing". The term "handing" is used to denote right or left sided elements of the airplane structure.

Steps in design to eliminate handing have taken a definite form. Designs incorporating these ideas are executed with servicing requirements governing the design. Such designs, on the other hand, need not be radical in construction. The simplicity afforded by good engineering of this sort is commendable.

The parts vitally affected by "handing" are as follows:

Wings and fillets, right and left.
Landing wheel, right and left.
Brakes and connections, right and left.
Ailerons, right and left.
Elevators, right and left.
Stabilizers, right and left.
Aileron controls, right and left.

Plus the usual number of subsidiary parts of the structure.

The "handing" of wing panels will always be subject to rights and lefts if an asymmetrical wing airfoil is used. If an airfoil similar to the N.A.C.A.0012, which is entirely symmetrical about the median line is used, the "handing" of the wing is eliminated. This is a very good feature. Wing panels cost money if they must be kept as spares. Cutting the number down reduces the investment 50%. This obviously applies to any other item.

By using a symmetrical airfoil for the tail plane the same saving is possible. Tail planes and the parts for the same are always easily damaged. During some time of the life of the plane they need replacement.

A saving of the same kind would be effected in the ailerons when used on a symmetrical wing section. These savings are worth considering.

As mentioned before, there is no need for brakes or landing wheels to be rights and lefts. A good example is shown in the Northrop planes using a right-handed gear on both legs. For quickness in servicing, brakes on the inside of the landing gear wheel makes adjustment difficult. With light metal parts and a delicate mechanism, the brake drums should be on the outside. This type of wheel is used on the Messerschmidt aircraft.

The ailerons receive their share of misuse in handling. Often the controls must be replaced. Symmetrical wings make it possible to use interchangeable parts with a slight modification in design. Advantages, such as these, are primarily only possible with metal aircraft. For field service under military conditions the number of parts on planes of this type would be reduced to the minimum.

FUEL TANKS

Fuel tanks are a part that need constant repair and inspection. For convenience the wing tanks should be built with a piano hinged edge. This is an easy way for a very good mounting with quick replacement. Fuselage tanks in metal aircraft offer no greater problem than in any other type of plane.

FILLETS

Under the normal service conditions the fillets, unless of very durable construction, will be a part that will require replacement. Such parts must be made removable to allow inspection, etc. Fillets, therefore, being of metal are made sectional and removable. Metal construction of the fillets allows a uniformity of the same. This makes for quick replacement. The fillet pieces are reinforced and preformed. Their wear is caused by denting and personnel damaging same in ground operations.

DOORS

Doors are subject to replacement frequently. All metal doors are simply and cheaply replaced. Metal construction of doors and jambs, being uniform, allows the door itself to be a standardized part.

WING LEADING EDGES

The leading edges of a wing in the vicinity of the propeller are subject to damage caused by flying stones kicked up by the propeller and the landing gear. The leading edges should be of heavy material to resist denting. Frequently in handling or hard landings the leading edge is damaged. To facilitate repair the leading edge in the Vultee V-1-A is made removable and a standard part. It can be replaced very quickly and easily.

FLAPS

The wing flaps at best are very frail structures from a structural standpoint. The light construction is necessitated by the requirements of low weight. In landing, the wing flaps receive considerable denting and damage from the action of the landing gear hurling stones into the flat surfaces. The flaps are a part that should be quickly detachable and subject to rapid replacement. This is found in the latest planes to be the cheapest and best way of maintenance.

TRAILING EDGES

In some wings the trailing edge is a separate demountable piece. The trailing edge of the wing receives wear from handling, if any. In the region of the slip stream, the trailing edge and the under side of the wing receive much denting from causes mentioned previously. Some trailing edges are removable up to the rear spar. Others are so made that they may be quickly repaired. Metal offers the quickest replacement and uniformity of a trailing edge part. This is a decided gain in cheap ground expense.

TRIMMING TABS

The trimmer tab is a small appendage on the aileron or the elevator and rudder. These trimmers have been made of metal frame and covered with fabric for cheapness. Metal trimmers are the best. Quick replacement should be possible.

DENTING

Light shell monocoques are always subject to denting. In taxiing, landing, and take off, rough field conditions account for this denting. All exposed parts subject to denting should be, if possible, strong enough to resist denting. Denting weakens the structure and is practically impossible to repair.

For protection against this, the under sides of metal wings in the critical areas are sometimes painted with a heavy rubberized or bitumastic paint. Sometimes a sheet of 1/8" thick sponge rubber is cemented to the parts affected.

Tail areas are always subject to denting. The tail areas on the underside are the place where the wear from the field conditions will be first noticeable. Denting fatigues the skin quickly. For safety the tail areas should be rapidly demountable, interchangeable, and quickly attached.

Metal tail areas without a doubt are the most advantageous. They may be stored for long periods without danger. They stand up better in handling than does a fabric covered area.

SKIN COVERS

External damage to the skin cover is not an easy task to repair quickly. It necessitates removing the injured area. To do this correctly requires the services of an experienced metal worker. The time and the cost of repairs of this kind are dependent on the extent of the damage.

Obviously any repair in a shell structure will take longer and cost more than to do a similar repair in a composite or wooden structure. On the other hand, damage of this kind is such that it does not happen frequently. If it is of such a severe nature, then the plane must be withdrawn from service. The probability is that other parts would be injured as well, necessitating a tie-up of the plane for repairs.

Skin covers are tough. When the skin is riveted into the structure and protected from damage on the ground, the only thing that can possibly damage the same is in taxiing or landing. This is a question of good piloting. Skin covers, if protected by labels, guards, and other devices, should not suffer from ground handling. The treatment of a delicate structure is merely a question of familiarity. The tyro ground man generally assumes that because the plane is of metal, it can stand all sorts of abuse. The metal plane is as delicate to handle as the fabric plane. The sooner that this fact is realized the less chance of its damage by the ground crew.

MAJOR CRASH REPAIRS

Major crashes, or injuries approaching this, are always a factory repair job. Certain forms of other aircraft construction may be repaired in the field quickly and with a minimum of cost. This, however, is an impossibility with a metal shell structure.

A major crash, first hand, requires a thorough inspection of all rivet holes for the least sign of stretching or shearing. Light shell structures are damaged more by rivets shearing than in any other way. The points of failure of a metal shell structure will be the joints. In certain types the fuselage is built in three sections. The probability is that the joints will be damaged and fail first.

FATIGUE

Metal shell structures must be inspected periodically for fatigue. In this respect the inspection of the interior of a metal wing is difficult. Some sort of optical or mechanical recording device would greatly facilitate the work. The inspection of the metal wing interior under present conditions is nearly impossible.

Fatigue will always be a difficult problem to combat where vibrations and heavy loads are combined. Fatigue can be caused by a number of things. Improper construction, faulty assembly, loose rivets, and corrosion all lend a hand to fatigue the structure. In the all-metal shell structure it is the question of fatigue that must be studied for parts that are difficult to service and inspect.

FITTINGS

The fittings of metal shell structures are always a source of trouble. The trouble experienced is not in the fitting but rather in the attachment. Inspection plates should be adjacent to the important fittings for safety. The dangers of electrolytic effects is also to be contended with. Dissimilar metals create this condition. Fittings are of chrome-molybdenum steel. They must be insulated from the dural by non-conductor material.

CORROSION

Corrosion prevention is covered in more detail in the "Aircraft Manual for Inspection, Maintenance and Repair" published by AVIATION PRESS of San Francisco. Suffice it to say, that all parts of the exterior of the all-metal airplane must be treated either anodically or else have a covering of Alclad alloy. Frequent inspection is necessary to prevent corrosion from being serious. The inspection requirements of the exterior is no greater than what may be expected of a fabric or wooden airplane exterior.

RIVET LOOSENESS

This danger is sometimes over estimated. Good rivets seldom work loose. Good metal aircraft have very few rivet failures. Inspection while driving the rivets at the factory prevents that. If the rivet does work loose it means that there is something seriously wrong with the other parts of the structure, causing the same to do so. Rivets are replaced easily in the field. Single shot riveters are used for repairs.

CRASHES AND REPAIRS

The question of which type is desirable in event of a crash has many pros and cons. The advocates of the welded steel or the wooden airplane structure have good sound arguments. The same applies to the all-metal shell structure. If the strength is equal in a hypothetical crash and the impact the same, there is doubt as to the best type. The probability is that both air frames would suffer the same extent.

Crash safety is largely a matter of structural arrangement. This is probably the soundest argument after all. There is no "best" type in a crash. The answer is that all things being equal neither type can outpoint the other very much.

CONCLUSION

The metal shell structure is here to stay. The permanence that metal affords in maintenance is desirable. Economy of part replacement is too great an item to overrule in favor of cheaper construction costs. If it were not so there is no question the leading air lines would have found that out by their investigations before purchasing all-metal planes. Even at the high price, which in time will be lower than they are today, the all metal monocoque or stressed skin airplane is the best plane for cheap maintenance for the air line. This does not apply to the private owner. Progress in the latter field, however, indicates that it may also be the case there as well in the near future.

CHAPTER X

WEIGHTS

This section is devoted to the more essential matters of weight control and the values of the same for the various metal parts and materials that make up the modern all metal airplane. The section is intended as a check on the values of weights that comprise the elements of structure rather than the miscellaneous accessory parts.

Weight control is necessary for many reasons. By increase in weight we reduce the performance in every phase of the same. By an increase in weight for a given strength we can reduce the possible load factor with given structural members. In short, if a given strength is possible with a given part and a minimum of weight, an increase in weight reduces the safety factor by the proportion of its increase. Therefore, a close study must be made of weight and weight control.

The government for military aircraft require a close check up on all weights for experimental aircraft. For production of service aircraft every fifth airplane of similar type must have a detailed weight report and check up. A penalty is imposed if the craft gains in weight, and a bonus is paid for every pound under weight with equal load factors. Excess weight is paid for very highly in any sort of performance in service aircraft; hence the high penalties for any excess increment of the same.

The normal materials available in the current market vary slightly from time to time. Consequently on large aircraft this variation must be carefully checked since the error in weight grows to larger proportions the larger the plane. The accompanying tables are correct to a close degree, but variations will be found slightly different in current manufactured materials. The tables, therefore, are intended for design purposes only.

STEEL TUBING MATERIAL.

Steel tubing is a widely used material in aircraft construction and will, by reason of its known strength properties, be used for parts of the structure subjected to high fatigue. Such points as engine mounts, landing gear struts, wing struts, and the like, are built of steel tubing in many all metal aircraft. It has the advantage of being welded readily with high strength. At present, while the newer designs are not necessarily using the tubing for fuselage construction (metal shell type being more widely used), the use of tubing for fuselage members will continue until a lighter and better material may be developed. This is not likely for some time.

Steel tubing is available in a number of different varieties of steel. Each variety is numbered and suitable for certain functions. The steel numbers have been designated by the S.A.E. The more common types are:

Carbon Steels	1025 (first figure denotes material;
Nickel Steels	2340 second figure is % of type of material;
Molybdenum Steels	4130 third figure denotes carbon content)

There are certain other combinations, but the above are the more commonly used in aircraft construction.

Ordinary commercial aircraft tubing is known as "1025", and has a tensile strength of 55,000 pounds with the chrome-molybdenum running up to 90,000 pounds. These steels may be improved with a heat treatment and the strength improved.

Fittings and streamline tubing of the production commercial type are generally of 1025 mild carbon steel, while chrome-molybdenum is used for fittings and highly stressed parts, and the like. The bolts and pins used in aircraft assembly are of nickel steel, or its various alloys, because of the higher strength in shearing qualities. As in other alloys, the harder the steel the less ductile, and vice versa. Chrome-molybdenum steel is much lighter in proportion to strength for certain types of construction by reason of its high strength. However, to secure the best weight advantage requires a highly specialized treatment in the design. In short, a fuselage of chrome-molybdenum may be built lighter for equal strength than a structure of similar dimensions using 1025 steel.

Steel is available in random lengths only when purchased from the supply firms. This is common practice since an extra cutting charge is required for sizes of a definite length. Tubing of the standard commercial type is seamless tubing. Such tubing is manufactured under the various government specifications as required for material of this sort.

ENGINEERING DATA

METAL SPECIFICATIONS OF RAW MATERIAL AND MANUFACTURED PARTS.

The specifications of the U. S. Army Air Corps Materiel Division form the basis of all materials, raw or manufactured, as used in current commercial airplane production and construction. The majority of concerns supplying materials of this sort maintain a rigid specification requirement, and very little variation may be expected. The Navy Department, Bureau of Construction, maintains likewise another set of rigid specifications for raw materials. The Naval specifications are in many cases primarily for raw material for their specific needs, but in general resemble the Army requirements.

The two branches of the services have adopted certain standard sizes and dimensions, and the majority of small parts utilized for aeronautic construction comply with the standard set up by the military requirements.

The Navy Department and the Army Materiel Division co-operate with the leading manufacturers and technical socieites for the establishment of specifications for all sorts of parts and material making up the metal airplane. The metal specifications are prepared through the aid of the various research and technical organizations, and the testing of the same as well as reports, results, and findings are then prepared by them into specification form, and the same distributed when the government agencies are in the act of procurement.

In the effort to standardize, certain items bear the "AN" prefix. This means that the joint committee of the Army and the Navy have agreed on a set standard, and the same is used in either service.

ALUMINUM DATA
TABLE FOR STRONG ALUMINUM ALLOYS

ALLOY	TENSILE STRENGTH (lbs. sq. in.)
51-SO	14,000-19,000
51-SW	30,000-40,000
51-ST	45,000-50,000
25-SO	23,000-35,000
25-SW	45,000-53,000
25-ST	55,000-63,000
17-SO	25,000-35,000
17-ST	55,000-63,000
B-17-SO	20,000-25,000
B-17-ST	42,000-50,000
A-17-ST	35,000-45,000
17-SO	25,000-35,000
17-ST	63,000-70,000
A-17-SO	20,000-35,000
24-ST	60,000
17-ST-Alclad	54,000
17-SRT	61,000
24-SRT Alclad	60,000

TEMPER DESIGNATIONS

2-SO	Commercially Pure Wrought Aluminum (Soft)
2-S4	Commercially Pure Wrought Aluminum ($\frac{1}{2}$ hard)
2-SH	Commercially Pure Wrought Aluminum (hard)
3-SO	Wrought Aluminum (Manganese Alloy) (soft)
3-S4	Wrought Aluminum (Manganese Alloy) ($\frac{1}{2}$ hard)
3-SH	Wrought Aluminum (Manganese Alloy) (hard)
17-SH	Hard Wrought Temper (Cold Work)
17-SO	Soft Annealed
25-SW	As Quenched
25-SO	Soft and Annealed
25-ST	Heat Treated Temper
24-SRT	Hardened Alclad Dural

WEIGHTS

PERCENTAGE CHEMICAL AND PHYSICAL PROPERTIES OF NATIONAL SHELBY AIRPLANE TUBING 1025.

Carbon	.20-.30
Manganese	.50-.80
Phosphorus	.045
Sulphur	.05
Yield Point	36,000 lbs. sq. inch
Elongation in 2"	22%
Specification	57-180-1A A.C.
W.D. 1025 Steel	

CHROME MOLYBDENUM

Carbon	.25-.30
Manganese	.40-.60
Phosphorus	.040
Sulphur	.045
Chromium	.80% to 1.10%
Molybdenum	.15 -.25
Yield Point	60,000 lbs sq. inch
Tensile Strength	95,000 lbs.
Elongation in 2"	10%
Specification	57-180-2a A.C.

STREAMLINE TUBING

Specification	57-183
Carbon	.25-.30
Manganese	.40-.60
Phosphorus	.040
Sulphur	.045
Chromium	.80 to 1.10%
Molybdenum	.15-.25
Yield Point	60,000 lbs.
Tensile Strength	95,000
Elongation in 2" min wall thickness less than 1/8"	5%
" " " " " " 1/4"	8%
" " " " " over 1/4"	10%

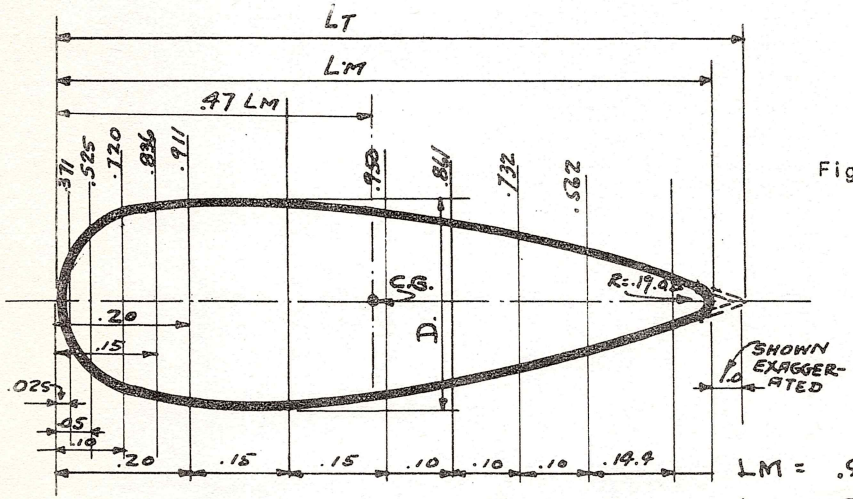


Figure 236

SEAMLESS STEEL TUBING PROFILE
A.C. SPECIFICATION NO. 57

LM = .944 LT
LT = D X 2.50
LM = .944 X 2.5D
LM = .236 X D

NOMINAL SIZE IN INCHES	MAJOR AXIS IN INCHES O.D.	MINOR AXIS D IN INCHES
1	1.348	.571
1 1/8	1.517	.643
1 1/4	1.685	.714
1 3/8	1.855	.786
1 1/2	2.033	.857
1 5/8	2.192	.929
1 3/4	2.360	1.000
1 7/8	2.528	1.071
2	2.697	1.143
2 1/4	3.035	1.287
2 1/2	3.372	1.429
2 3/4	3.708	1.571
3	4.045	1.714

WEIGHT OF TUBES STREAMLINED SHAPE

To find the weight of a streamline tube in steel take the nominal size which is the equivalent diameter of a steel tube and find the weight or the steel tube by refering to the table on the same.

ANGLES 17ST DURALUMINUM

SIZE	WT. PER LINEAR FT. LBS.
1/2" x 1/2" x 1/8"	.126
5/8" x 5/8" x 3/32"	.125
3/4" x 3/4" x 1/8"	.238
1" x 1" x 1/8"	.320
1-1/4" x 1-1/4" x 1/8"	.346
1-1/4" x 1-1/4" x 3/16"	.521
2" x 2" x 3/16"	.828
3" x 3" x 1/4"	2.568

TEES 17ST DURALUMINUM

SIZE	WT. PER LINEAR FT. LBS.
1-1/4" x 1" x 1/8"	.310
1-31/32" x 1-1/2" x 3/16"	.712
2" x 1-1/2" x 3/16"	.806
1-31/32" x 2-25/64" x 3/16"	1.035
2-9/16" x 1-29/64" x 3/16"	.997
2-9/16" x 1-1/8" x 3/16"	.769
1-1/2" x 1-1/4" x 1/8"	.440
2" x 2" x 1/4"	1.250
2-1/2" x 1-1/4" x 3/16"	1.07
3" x 3" x 3/8"	2.89
4" x 4" x 3/8"	3.82

CHANNELS 17ST DURALUMINUM

SIZE	WT. PER FT. IN LBS.
3/8" x 3/8" x .032	.035
7/16" x 3/8" x .032	.042
5/8" x 9/32" x .040	.055
5/8" x 7/16" x .102	.172
3/4" x 1/2" x 1/8"	.220
3/4" x 1/2" x 1/8"	.225
3/4" x 3/8" x 1/16"	.118
1 x 7/8" x 1/8"	.358
1-1/2" x 1-1/2" x 5/32"	.815
3" x 1.41" x .17"	1.41
4" x 1.65" x 2.47"	2.33
4" x 1.73" x .320"	2.66
5" x 1.75" x .19"	2.35
6" x 1.92" x .20"	2.98

WEIGHTS

HEAT TREATED 17ST DURALUMIN

B & S GAUGE	DECIMAL INCHES	WT. PER SQ. FT.
6	.162	2.36
8	.1285	1.87
10	.1019	1.46
11	.0907	1.32
12	.0808	1.18
14	.0641	.94
16	.0508	.75
18	.0403	.60
20	.032	.46
22	.0253	.38
24	.0201	.30
26	.0159	.24
28	.0126	.183
30	.010	.15

17ST ALCLAD CORRUGATED SHEET DURALUMIN

B & S GAUGE	DECIMAL INCHES	WT. PER SHEET
20	.032	11.4
22	.0253	8.8
24	.0201	6.64
27	.014	4.9

Sheet Size 23-1/4" x 120"

SQUARE TUBING 17ST DURALUMIN

SIZE	WALL THICKNESS	WT. LINEAR FT. IN LBS.
3/8" x 3/8"	.022	.0381
9/16" x 9/16"	.040	.0906
3/4" x 3/4"	.049	.1751
1" x 1"	.036	.1648
1" x 1"	.062	.3010

ALUMINUM SHEET 2S4 Half Hard A.C.Specifications 57-151

GAUGE	DECIMAL INCHES	SHEET SIZE	WT. PER SHEET
8	.128	12 x 72"	10.87
10	.102	"	8.64
11	.091	"	7.68
12	.081	"	6.84
14	.064	"	5.42
16	.051	"	4.29
18	.040	"	3.41
20	.032	"	2.70
22	.025	"	2.14
24	.020	"	1.70
26	.016	"	1.35
28	.013	"	1.60

MACHINE SCREWS AND NUTS OF STEEL

SIZE	WT. WITH NUTS
0-80	.0005
1-72	.001
2-64	.002
3-56	.002
4-48	.0025
5-44	.0025
6-40	.0045
8-36	.0045
10-32	.0046

Aluminum Machine Screws and Nuts are figured at approximately one third the weight. Material 17ST

BRASS SCREEN

22 mesh per inch (.015)	.340 lbs sq. ft.
32 mesh per inch (.007)	.160 lbs sq. ft.
110 mesh per inch (.004)	.143 lbs sq. ft.

SPRING FLAT STEEL WIRE

GAUGE B.W.G.	LBS. SQ. FT.
20	1.428
18	1.999
16	2.652

WEIGHTS

TERNE PLATE OR TIN (Lbs. sq. ft.)

(Lead coated mild sheet steel)

GAUGE	TERNE PLATE	TIN
26 ga	.72	.69
24 ga	.88	.88
20 ga	1.41	1.38

SHEET STEEL

B.W.G. GAUGE	LBS. SQ. FT.
24	.90
22	1.144
20	1.43
18	2.00
16	2.70
14	4.08
12	5.10
10	7.65

FLAT WASHERS

SIZE	BOLT SIZE	WT. STEEL	WT. ALUMINUM
1	27		
2	18	.0013	.0004
3	10	.0014	.00043
4	2	.0016	.00053
5	1/4	.0031	.00075
6	5/16	.0038	.00094
7	3/8	.0043	.00014
8	7/16	.0101	.003
9	1/2	.011	.0036
10	9/16	.0192	.0061
11	5/8	.0212	.0071
12	11/16	.0228	.0077
13	3/4	.0357	.0119
14	7/8	.041	.013
15	1	.0555	.0188

WEIGHTS

SHEET STRIP STEEL

Mild Carbon A.C. Specifications Cold Rolled 10201C or 57-136-3

B.W.G. NUMBER	DECIMAL INCHES	WT. PER SQ. FT.	WT. SHEET 12" x 72"
24	.022	.897	5.37
22	.028	1.142	6.84
20	.035	1.428	8.57
18	.049	2.000	11.94
16	.065	2.651	15.90
14	.083	3.386	20.28
	3/32"	3.83	22.90
	1/8"	5.10	30.60
	5/32"	6.38	38.20
	3/16"	7.65	45.90
	1/4"	10.20	61.20

CHROME MOLYBDENUM STRIP STEEL

B.W.G.	DECIMAL	WEIGHT
21	.032	1.284
18	.049	2.000
16	.0625	2.651
13	.095	3.601
11	.120	5.10

COPPER SHEET

10 oz.	.013 inches	.625 lbs. sq. ft.
14 oz.	.018 "	.875 lbs. sq. ft.
16 oz.	.021 "	1.000 lbs. sq. ft.
18 oz.	.024 "	1.125 lbs. sq. ft.

ALUMINUM ALLOY BOLTS AND NUTS

SIZE	HEX. HEAD BOLT	HEX. NUT CASTELLATED
6-40	.004	.002
10-32	.0042	.003
1/4-28	.011	.0043
5/16-24	.006	.005
3/8-24	.0076	.006

ALUMINUM TUBING			
DIAMETER"	DECIMAL	TEMPER	WT. PER FOOT
3/16	.035	2 SH	.019
3/16	.032	2 SO	.018
3/16	.022	2 SH	.013
1/4	.065	2 SH	.044
1/4	.049	2 SH	.036
1/4	.035	2 SH	.027
1/4	.032	2 SH	.025
5/16	.035	2 SO	.036
5/16	.065	2 SH	.054
5/16	.049	2 SH	.047
5/16	.035	2 SO	.035
5/16	.032	2 SH	.032
3/8	.028	2 SO	.037
3/8	.049	2 SO	.058
3/8	.035	2 SH	.043
3/8	.032	2 SO	.040
7/16	.028	2 SH	.047
7/16	.035	2 SH	.051
1/2	.028	2 SO	.051
1/2	.065	2 SH	.104
1/2	.035	2 SH	.059
5/8	.028	2 SO	.063
5/8	.049	2 SH	.103
3/4	.050	2 SH	.460
3/4	.065	2 SH	.163
3/4	.035	2 SH	.091
7/8	.049	2 SH	.151
1	.035	2 SH	.123
1	.065	2 SH	.222
1	.049	2 SH	.170
1 1/4	.065	2 SH	.270
1 1/4	.035	2 SH	.155

ALUMINUM TUBING			
DIAMETER"	DECIMAL	TEMPER	WT. PER FOOT
1 1/4"	.028	2SH	.125
1 5/16	.049	2SH	.227
1 3/8	.049	2SH	.240
1 3/8	.028	2SH	.138
1 1/2	.065	2SH	.330
1 1/2	.049	2SH	.260
1 1/2	.035	2SH	.180
1 5/8	.035	2SH	.190
1 3/4	.065	2SH	.390
1 3/4	.049	2SH	.300
1 3/4	.028	2SH	.178

A.C. SPECIFICATION 57-187
ALUMINUM ALLOY 175 ALLOY 5% FOR ADDITIONAL WEIGHT

B.W.G.	DEC.INS	NATIONAL- SHELBY AIRCRAFT TUBING														
		OUTSIDE DIAMETER IN INCHES														
		1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	1 3/4	2	2 1/4	2 1/2	2 3/4	3
20	.035	.22	.28	.34	.40	.46										
18	.049	.30	.38	.47	.55	.63	.72									
16	.065	.38	.49	.61	.72	.83	.94	1.05	1.16	1.27	1.49	1.71				
14	.083			.75	.89	1.03	1.18	1.32	1.46	1.60	1.88	2.16				
13	.095				1.01	1.17	1.33	1.49	1.65	1.82	2.14	2.46	2.78	3.11	3.43	3.75
12	.109				1.14	1.32	1.51	1.69	1.88	2.06	2.43	2.80	3.17	3.54	3.91	4.29
11	.120				1.23	1.44	1.64	1.84	2.05	2.25	2.66	3.07	3.48	3.88	4.29	4.70
10	.134										2.94	3.40	3.86	4.31	4.77	5.22
5/32"	.156										3.39	3.92	4.45	4.98	5.51	6.04
3/16"	.188										3.98	4.62	5.26	5.90	6.53	7.17
1/4"	.250												6.80	7.65	8.50	9.35
5/16"	.313															
3/8"	.375															

THE ABOVE WEIGHTS ARE FOR SQUARE TUBING. (STEEL) IN POUNDS

RECTANGULAR TUBING WEIGHTS DETERMINED AS FOLLOWS - ADD LINEAR DIMENSIONS OF 4 SIDES TOGETHER AND DIVIDE BY FOUR AND TAKE WEIGHT OF CORRESPONDING SQUARE TUBE.

B.W.G. = BIRMINGHAM WIRE GAUGE DEC. INS = DECIMAL INCHES.

NATIONAL SHELBY AIRCRAFT TUBING

OUTSIDE DIAMETER IN INCHES

B.W.G. GAUGE	DEC. SIZE.	1/4"	5/16"	3/8"	7/16"	1/2"	5/8"	3/4"	7/8"	1"	1 1/8"	1 1/4"	1 3/8"	1 1/2"	1 5/8"	1 3/4"	1 7/8"	2	2 1/8"	2 1/4"	2 3/8"	2 1/2"	2 5/8"	2 3/4"	2 7/8"	3"	
22	.028	.066	.085	.104	.123																						
20	.035	.080	.104	.127	.151	.17	.22	.27	.31	.36	.41	.45	.50	.55													
18	.049	.105	.138	.171	.203	.24	.30	.37	.43	.50	.56	.63	.69	.76	.82	.89	.96	1.02	1.09	1.15	1.22	1.28					
16	.065	.128	.172	.215	.259	.30	.39	.98	.56	.65	.74	.82	.91	1.00	1.08	1.17	1.26	1.34	1.43	1.52	1.60	1.69	1.78	1.86			
14	.083		.203	.259	.314	.37	.48	.59	.70	.81	.92	1.03	1.15	1.26	1.37	1.48	1.59	1.70	1.81	1.92	2.03	2.14	2.25	2.36	2.47	2.59	
13	.095			.282	.348	.41	.54	.66	.79	.92	1.05	1.17	1.33	1.43	1.55	1.68	1.81	1.93	2.06	2.19	2.31	2.44	2.57	2.69	2.82	2.95	
12	.109				.382	.46	.60	.75	.89	1.05	1.18	1.33	1.47	1.62	1.76	1.91	2.06	2.20	2.35	2.49	2.64	2.78	2.93	3.07	3.22	3.37	
11	.120				.407	.49	.65	.81	.97	1.18	1.29	1.45	1.67	1.77	1.93	2.09	2.25	2.41	2.57	2.73	2.89	3.05	3.21	3.37	3.53	3.69	
10	.134					.52	.70	.88	1.06	1.24	1.42	1.60	1.78	1.95	2.13	2.31	2.49	2.67	2.85	3.03	3.21	3.39	3.56	3.74	3.92	4.10	
5/32"	.156						.78	.99	1.20	1.41	1.62	1.83	2.03	2.24	2.45	2.66	2.87	3.08	3.29	3.49	3.70	3.91	4.12	4.33	4.54	4.75	
3/16"	.188						.88	1.13	1.38	1.63	1.88	2.13	2.38	2.63	2.88	3.13	3.38	3.63	3.88	4.13	4.38	4.63	4.88	5.13	5.38	5.63	
7/32"	.219								1.53	1.83	2.12	2.41	2.70	2.99	3.29	3.58	3.87	4.16	4.45	4.75	5.04	5.33	5.62	5.91	6.21	6.50	
1/4"	.250								1.70	2.00	2.34	2.67	3.00	3.34	3.67	4.01	4.34	4.67	5.01	5.34	5.67	6.01	6.34	6.68	7.01	7.34	
9/32"	.281										2.53	2.91	3.29	3.66	4.04	4.41	4.79	5.16	5.54	5.91	6.29	6.66	7.04	7.92	7.79	8.17	
5/16"	.313										2.71	3.13	3.55	3.96	4.38	4.83	5.21	5.63	6.05	6.97	6.88	7.30	7.72	8.14	8.55	8.97	
3/8"	.375											3.50	4.01	4.51	5.01	5.51	6.01	6.51	7.01	7.51	8.01	8.51	9.01	9.51	10.01	10.51	

DEC. INS. = DECIMAL INCHES B.W.G. BIRMINGHAM WIRE GAUGE

ROUND TUBING

WEIGHTS IN POUNDS

ALUMINUM PIPE DATA

STANDARD ALUMINUM PIPE (I.P.S.)

SIZE	OUTSIDE DIAMETER	INSIDE DIAMETER	WT. PER FOOT
1/8"	.405	.270	.083
1/4"	.540	.364	.145
3/8"	.675	.494	.193
1/2"	.840	.623	.290
3/4"	1.05	.824	.387

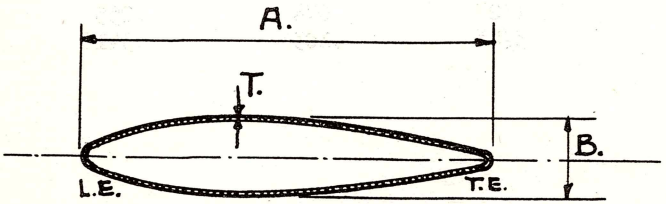
STANDARD ALUMINUM PIPE FITTINGS (Weights)

SIZE	90 DEGREE ELBOWS	TEES	PLUGS	COUPLING
1/8"	.056	.040	.008	.023
1/4"	.049	.072	.016	.031
3/8"	.087	.140	.027	.042
1/2"	.139	.194	.047	.078
3/4"	.218	.287	.069	.123

	CAPS	UNIONS
1/8"	.015	.099
1/4"	.016	.158
3/8"	.056	.172
1/2"	.074	.255
3/4"	.103	.341

MAJOR AXIS "A"	MAJOR AXIS "B"	WALL THICK-NESS IN INCHES	T.E. RADIUS IN IN-CHES	WEIGHT LBS. FOOT	AREA OF WALL SQ. INS.	EQUIV. DIA. OF ROUND TUBE"	FINENESS RATIO	ALLOYS AVAIL-ABLE
1.219	.414	.035	.047	.109	.091	.844	2.94	25-35
1.625	.375	.032	.063	.131	.108	1.106	4.33	" "
1.875	.375	.035	.012	.166	.140	1.310	5.00	ALL
2.700	1.114	.058	.160	.429	.354	2.00	2.36	"
2.750	1.125	.049	.201	.388	.320	2.13	2.44	"
2.875	1.000	.050	.231	.384	.320	2.088	2.87	25-35
3.125	.375	.032	.015	.247	.206	2.049	8.34	" "
3.125	1.118	.049	.179	.407	.339	2.253	2.63	ALL
3.125	1.118	.049	.045	.436	.360	2.313	2.63	25-35
3.125	1.118	.057	.171	.456	.380	2.253	2.63	ALL
3.125	1.118	.032	.094	.271	.400	2.313	2.63	"
3.125	1.118	.057	.094	.456	.380	2.253	2.63	"
3.125	1.118	.090	.281	.790	.658	2.327	2.63	"
3.350	1.500	.065	.123	.634	.521	2.625	2.23	"
3.375	1.430	.065	.207	.601	.497	2.500	2.36	"
3.710	1.572	.065	.233	.674	.548	2.750	2.36	"
3.710	1.572	.072	.226	.732	.612	2.750	2.42	"
4.008	1.760	.095	.290	1.070	.901	3.125	2.31	"
4.018	1.760	.065	.320	.786	.648	3.024	2.28	"
4.050	1.716	.083	.243	.933	.770	3.040	2.36	"
4.384	1.860	.083	.270	.982	.810	3.194	2.36	"
4.384	1.860	.095	.258	1.162	.968	3.750	2.36	"
4.720	2.000	.095	.285	1.270	1.050	3.250	2.36	"
5.428	2.300	.104	.328	1.605	1.338	4.018	2.36	"
5.428	2.300	.148	.444	2.180	1.817	4.058	2.36	"
6.474	2.760	.134	.402	2.330	1.942	4.747	2.34	"

STREAMLINE DURAL TUBING



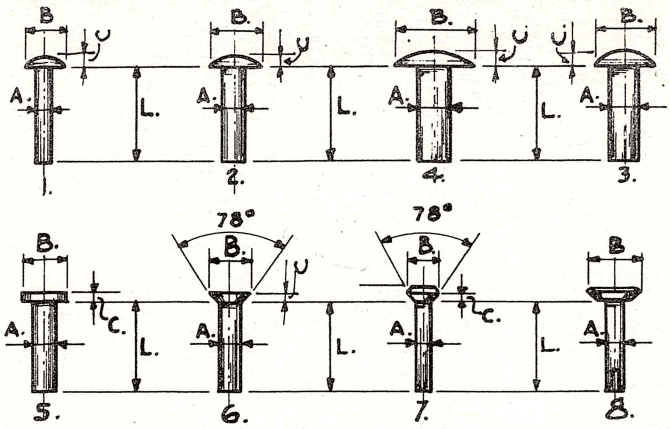


Figure 237

No.	Kind	B	C	Head Radius	Edge Radius	Oval Depth
1.	Button Head–1.75A		.75A	.885A		
2.	Round Head–2A		.75A	1.042A		
3.	Mushroom Head–2A		.625A	1.634A	.50A	
4.	Brazier Head–2.5A		.50A	1.8125A		
5.	Flat Head—2A		.4A			
6.	Ctsk. Head—1.81A		.5A		L signifies length	
7.	Ctsk. Oval Head–1.81A		.5A			.25A
8.	Tubular Shank—.5A–This rivet made in several sizes and heads and tubular dimensions					

COMMON RIVETS OF ALUMINUM AND ALLOYS

RIVET WEIGHTS

ROUND HEAD

LENGTH	RIVET DIAMETER							
	1/16	3/32	1/8	5/32	3/16	1/4	5/16	3/3
1/8"	13,900							
3/16	10,950	4,170	2,000					
1/4	9,000	3,540	1,740	990	630			
5/16	7,600	3,060	1,515	885	565			
3/8	5,960	2,650	1,340	800	515	280		
7/16				725				
1/2	4,820	2,140	1,115	665	435	215	124	
5/8		1,795	945	570	375	190	110	
3/4		1,560	825	500	330	170	96	64
7/8						153	90	
1			625	400	270	140	83	54

BRAZIER HEAD

LENGTH	RIVET DIAMETER			
	1/16	3/32	1/8	5/32
3/32"	16,120			
1/8	13,900			
3/16	10,950	4,170	2,000	1,130
1/4	8,900	3,540	1,740	990
5/16	7,600	3,060	1,515	
3/8	5,960	2,650	1,340	800
1/2	4,820	2,140	1,115	665
9/16				
5/8				
3/4				
1				

FLAT HEAD

LENGTH	RIVET DIAMETER		
	3/32	1/8	1/4
3/16	4,170		
1/4	3,540	1,740	
5/16	3,060	1,515	
3/8	2,650	1,340	
1/2	2,140	1,115	215

BUTTON HEAD

LENGTH	RIVET DIAMETER
	1/4
5/8	190
3/4	170
1	140

All the above tables indicate the number of pieces per pound.

COUNTERSUNK HEAD

LENGTH	RIVET DIAMETER						
	1/8	5/32	3/16	1/4	5/16	3/8	1/2
3/16	3,250						
1/4	2,520	1,540					
5/16		1,300					
3/8			750				
1/2	1,400		595	315	190		
9/16				285			
5/8			495	260			
3/4			420	225	140	93	49
7/8				197			
1			325	175	110	74	

TUBULAR RIVETS

LENGTH	RIVET DIAMETER		
	9/64	5/32	3/16
1/4	1,440	1,250	859
3/8	1,190	965	667
1/2	940	789	546

All the above tables indicate the number of pieces per pound.

SMALL METAL PARTS

LOCK WASHERS FOR S.A.E. STANDARD BOLTS (Weight per 1000)

BOLT SIZE	WT. PER 1000
4	1/5 lb.
6	1/4 lb.
8	3/8 lb.
10	3/4 lb.
12	1 lb.
1/4	2 lb.
3/8	6 lb.
1/2	10 lb.

PLAIN WASHERS

These may be of steel or brass. Steel may be cadmium plated. They are available in standard bolt sizes. AN Spec.-960.

CLEVIS PINS

These are available of steel A-N Specification. The strength in tension is 125,000 pounds. The length is measured from the under side of the head to the inside edge of the safety wire hole. They are available in sizes from 1/8" up, graduated in 1/16" difference up to 1/2". The length is available in 1/32" variation from 7/32" to 31/32".

PARKER SCREWS

These are metal screws with special threads. They are used to fasten fabric and metal surfaces for non-structural purposes.A hole is driven and the screw driven in. They are available in round or binding head.

TINNED AIRCRAFT WIRE

SIZE DIA.	STRENGTH	FT. PER LB.
.135	3290	20.7
.120	2670	26.3
.105	2090	34.3
.091	1600	44.8
.080	1260	59.1

STANDARDS FOR WIRE GAUGES

NO. OF WIRE GAUGE	B. & S.	B.W.G.	U.S. STD. FOR PLATE
0000	.46	.454	.406
000	.409	.425	.375
00	.364	.38	.343
0	.324	.34	.312
1	.289	.30	.281
2	.257	.284	.265
3	.229	.259	.250
4	.204	.238	.234
5	.181	.220	.218
6	.162	.203	.203
7	.144	.180	.187
8	.128	.165	.171
9	.114	.148	.156
10	.101	.134	.140
11	.090	.120	.125
12	.080	.109	.109
13	.071	.095	.093
14	.064	.083	.078
15	.057	.072	.070
16	.050	.065	.062
17	.045	.058	.056
18	.040	.049	.050
19	.035	.042	.043
20	.031	.035	.037
21	.028	.032	.034
22	.025	.028	.031
23	.022	.025	.028
24	.020	.022	.025
25	.017	.020	.021
26	.015	.018	.018
27	.014	.016	.017
28	.012	.014	.015
29	.011	.013	.014
30	.010	.012	.012

The above gauges are in use throughout the United States.
The dimensions of sizes are Decimal Parts of an Inch.

MISCELLANEOUS SMALL PARTS

LOCK WASHERS

SIZE	BOLT SIZE IN INCHES	WEIGHT (Steel)
17	1/2	.0141
16	7/16	.0046
15	3/8	.0051
14	5/16	.0040
13	5/8	.0128
12	12	.0012
11	6	.0002
10	4	.0001
9	11/16	.0014
8	9/16	.0072
7	1/2	.0064
6	7/16	.0048
5	3/8	.0034

CLEVIS PIN WEIGHTS

SIZE	WEIGHT PER INCH
1/8"	.0035
3/16	.008
1/4	.015
5/16	.021
3/8	.031
7/16	.043
1/2	.056
9/16	.070
5/8	.087

TAPER PINS

SIZE	WEIGHT PER INCH
00	.0042
0	.0051
1	.0060
2	.0072
3	.0085
4	.013
5	.016
6	.024

DURAL TUBING DATA

SQUARE TUBING (ROUNDED CORNERS)

SIZE	GAUGE	WEIGHT PER FT.
.317	.028	.035
.375	.022	.037
.380	.028	.044
.500	.022	.061
.5625	.040	.088
.750	.049	.170
1.0	.036	.160
1.0	.058	.267
1.0	.065	.301
1.125	.036	.176
1.125	.049	.254
1.125	.058	.303
1.125	.065	.333
1.375	.036	.232
1.375	.048	.314
1.375	.065	.408

RECTANGULAR TUBING (ROUNDED ENDS)

SIZE OUTSIDE	GAUGE	WEIGHT PER FT.
.750 x .406	.035	.083
.750 x .406	.049	.107
1.0 x .3125	.020	.056
1.0 x .3125	.032	.088
1.0 x .406	.035	.104
1.31 x .406	.035	.133
1.31 x .406	.049	.173
1.53 x .343	.032	.136
2.99 x 1.25	.157	1.300
6.00 x 3.12	.065	1.210
6.00 x 3.20	.072	1.220

Above tubing is available in 2S, 3S, and other dural alloys.

HALL AIRCRAFT TUBING HA-500

PATTERN	SIZE	GAUGE	WT. PER FOOT
12-19	3/4" x 1-1/4"	.036	.1389
16-16	1 x 9/16"	.051	.2480
20-16	1-1/4 x 1-13/16"	.051	.2970
4-27	1/4 x 9/16"	.014	.0228
4-24	1/4 x 9/16"	.020	.0317
5-26	5/16 x 5/8"	.016	.0297
5-24	5/16 x 5/8"	.020	.0366
6-24	3/8 x 11/16"	.020	.0412
6-22	3/8 x 11/16"	.024	.0489
6-21	3/8 x 11/16"	.028	.0606
7-24	7/16 x 13/16"	.020	.0489
7-22	7/16 x 13/16"	.024	.0582
7-21	7/16 x 13/16"	.028	.0716
8-24	1/2 x 7/8"	.020	.0537
8-22	1/2 x 7/8"	.024	.0640
8-21	1/2 x 7/8"	.028	.0781
8-20	1/2 x 7/8"	.032	.0889

HALL AIRCRAFT TUBING HA-529

10-20	5/8 x 1-1/2"	.032	.0967
12-19	3/4 x 1-5/8"	.036	.1230
14-18	7/8 x 1-7/8"	.040	.1586
16-17	1 x 2"	.045	.1957
20-16	1-1/4 x 2-1/2"	.051	.2770
8-24	1/2 x 1-1/4"	.020	.0496
8-22	1/2 x 1-1/4"	.024	.0596
10-24	5/8 x 1-3/8"	.020	.0473
10-22	5/8 x 1-3/8"	.024	.0568
10-21	5/8 x 1-3/8"	.028	.0697
10-20	5/8 x 1-3/8"	.032	.0798
12-24	3/4 x 1-1/2"	.020	.0651
12-22	3/4 x 1-1/2"	.024	.0783
12-21	3/4 x 1-1/2"	.028	.0956
12-21	3/4 x 1-1/2"	.032	.1093

DURAL TUBING DATA

SQUARE SEAMLESS TUBING

SIZE	GAUGE	WEIGHT PER FT.
7/16	.049	.090
1/2	.047	.135
3/4	.062	.205
1	.062	.279
1-1/4	.062	.254
1-1/2	.062	.428
1-3/4	.062	.503
2	.062	.577

RECTANGULAR TUBING

SIZE	GAUGE	WEIGHT PER FT.
1/2 x 1-3/4	.028	.147
3/4 x 1-1/2	.049	.247
1 x 2	.083	.564
1-1/4 x 2-1/2	.083	.718
1-1/2 x 4	.093	1.200
2 x 5	.125	2.026

OCTAGON TUBING

OUTSIDE DIA.	GAUGE	WEIGHT PER FT.
1.410	.160	.500

ZEE BAR SHAPES

SIZE	WEIGHT PER FT.
1-1/4 x 3/4 x 3/32"	.295
2 x 1-1/4 x 3/16"	.950
2-3/8" x 1-1/4 x 3/16"	1.030
3 x 2-11/16 x 1/4"	2.400

DECIMAL EQUIVALENTS OF B.W.G.

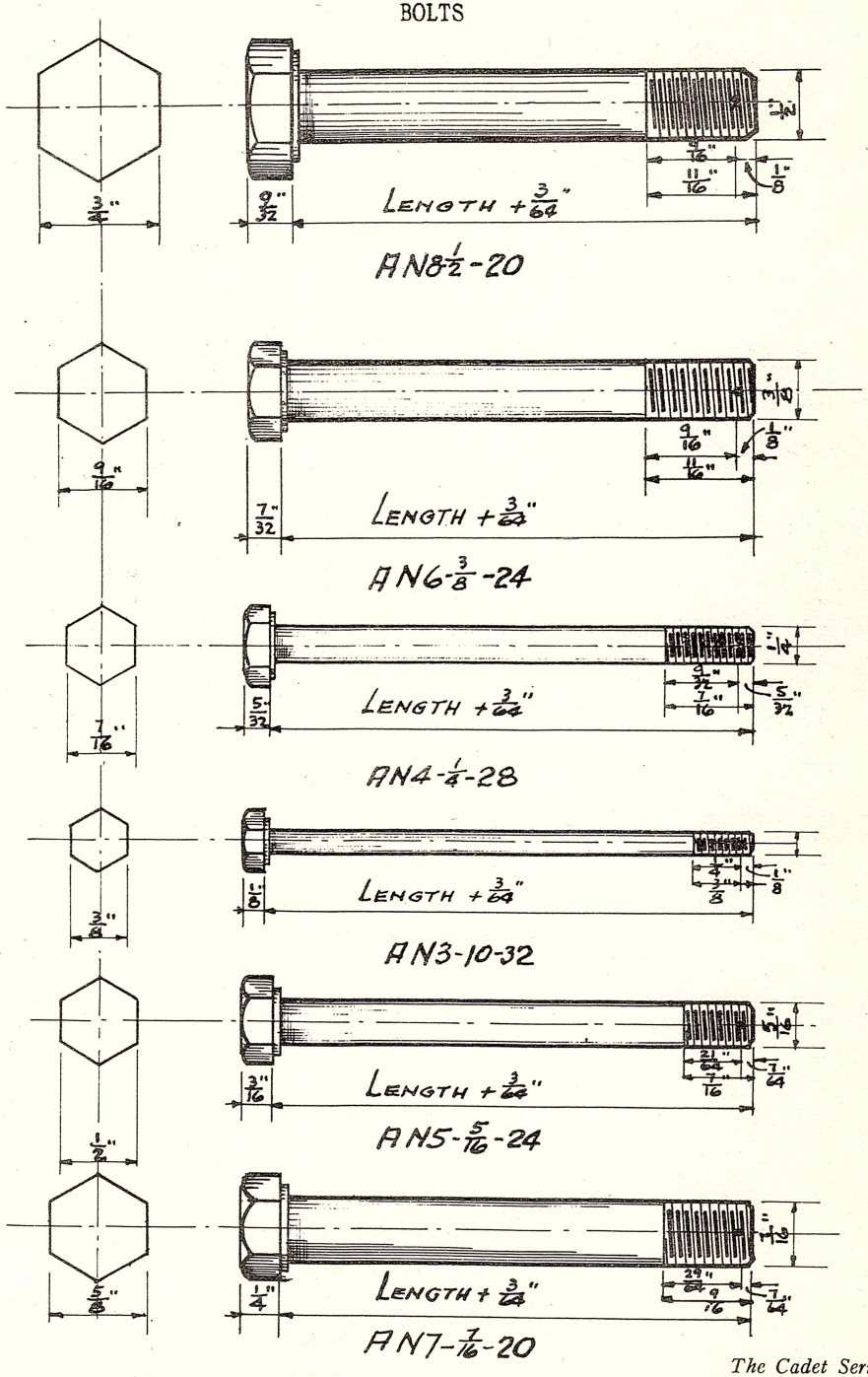
GAUGE	DECIMAL EQUIVALENT (INCHES)
30	.012
29	.013
28	.014
27	.016
26	.018
25	.020
24	.022
23	.025
22	.028
21	.032
20	.035
19	.042
18	.049
17	.058
16	.065
15	.072
14	.083
13	.095
12	.109
11	.120
10	.134
9	.148
8	.165
7	.180
6	.203
5	.220
4	.238
3	.259
2	.284
1	.300
0	.340
00	.380
000	.425
0000	.454

1/64		.0156		33/64	.5156
1/32		.0312		17/32	.5312
3/64		.0468		35/64	.5468
1/16		.0625		9/16	.5625
5/64		.0781		37/64	.5781
3/32		.0937		19/32	.5937
7/64		.1093		39/64	.6093
1/8		.125		5/8	.6250
9/64		.1406		41/64	.6406
5/32		.1562		21/32	.6562
11/64		.1718		43/64	.6718
3/16		.1875		11/16	.6875
13/64		.2031		45/64	.7031
7/32		.2187		23/32	.7187
15/64		.2343		47/64	.7343
1/4		.2500		3/4	.7500
17/64		.2656		49/64	.7656
9/32		.2812		25/32	.7812
19/64		.2968		51/64	.7968
5/16		.3125		13/16	.8125
21/64		.3281		53/64	.8281
11/32		.3437		27/32	.8437
23/64		.3593		55/64	.8593
3/8		.375		7/8	.8750
25/64		.3906		57/64	.8906
13/32		.4062		29/32	.9062
27/64		.4218		59/64	.9218
7/16		.4375		15/16	.9375
29/64		.4531		61/64	.9531
15/32		.4687		31/32	.9687
31/64		.4843		63/64	.9843
1/2		.5000		1	1.000

THE DECIMAL EQUIVALENTS OF AN INCH

Figure 238

BOLTS



AIRCRAFT STANDARD BOLTS

These bolts are standard throughout the aircraft industry and are made in strict accordance with the Army and Navy Standard Specifications. The material is 2330 Nickel Steel which is heat treated to 125,000 pounds per square inch. The bolts are cadmium plated, and are drilled for a safety lock cotter key. The length is measured from under the head to the end of the bolt. The bolts are available commercially in lengths up to 7" and the various sizes as detailed.

BEARING STRENGTH OF 17S SHEET

	RIVET SIZES				
SINGLE SHEAR	1/16"	3/32"	1/8"	5/32"	3/16"
STRENGTH IN LBS.	92	207	368	575	828
SHEET THICKNESS					
.012	56	84	112	140	168
.016	75	112	150	187	225
.020	94	141	181	234	281
.030	117	176	234	293	351
.035	141	211	281	352	422
.040	164	246	328	410	492
.045	188	281	376	469	563
.051	211	316	422	527	633
.057	239	359	478	598	717
.064	267	401	534	668	801
.072	300	451	600	750	900

The above table based on 75,000 lbs. bearing per sq. inch.
The rivet shear is allowed at 30,000 lbs. per sq. inch.
The values for 24S sheet are increased approximately 30% of the above.

WEIGHT OF ALLOYS

ALLOY	WT. PER CUBIC INCH
2S	.098
3S	.099
4S	.098
17S	.101
24S	.100
25S	.101
51S	.097
53S	.097

MECHANICAL PROPERTY SPECIFICATIONS DURAL ALLOYS

MATERIAL	MIN. TENSILE STRENGTH IN POUNDS SQ. INCH
17SO	35,000
17ST	55,000
17SRT	55,000
24ST	62,000
24SRT	65,000
51SO	19,000
51SW	30,000
51ST	45,000
Alclad 17SO	30,000
Alclad 24SO	30,000
Alclad 17ST	50,000
Alclad 17SRT	50,000
Alclad 24ST	56,000
Alclad 24SRT	58,000

QUESTIONAIRE

Upon completing a study of this text the reader can examine the extent and thoroughness of his efforts by his ability to satisfactorily answer the questions herein presented.

CHAPTER I

1. Give a resume of the early attempts of the pioneers in metal airplane construction in the U. S. A.
2. What brought to the forefront the necessity that aircraft be constructed of metal?
3. Describe the essential differences between all metal aircraft, aircraft of composite construction, and the wooden or plywood airplane structures.
4. What factors determine to the operator the material of the airplane that is purchased?
5. What is meant by servicing and construction costs?
6. Compare the durability of wooden and metal aircraft.
7. Make a comparison of the repair costs on either type.
8. How do geographical factors influence the type of airplane used?
9. What inherent weaknesses has wood? Name them.
10. What is the trend in the use of materials for airplane construction in the near future?

CHAPTER II

11. Enumerate the physical characteristics and properties of aluminum alloys as used in current airplane fabrication.
12. What is dural? Where is it used?
13. Who used it first and where?
14. What is meant by chemically pure aluminum?
15. Give a rough comparison of the properties of wood, duralumin and steel.
16. Give the physical composition of various duralumin alloys.
17. What is meant by 24 SRT? Describe its properties.
18. What is meant by workability?
19. What does the suffix "SO" or "SH" mean?
20. Describe Alclad. Where is it used?
21. What do we mean by corrosion resistance? How is it prevented?
22. Describe heat treatment.
23. Why is heat treatment used?
24. Where are dural alloys used aside from airplane structures in the aeronautic manufacturing industry?
25. What is Dow metal? Describe its properties.
26. What is magnesium? Where is it used? Why?

27. Where is Electron metal used?
28. What is the difference between Electron metal working and other dural alloys?
29. What is a forging? Why are they used?
30. What is meant by limitations in bending and forming?
31. Name some places on the airplane where a casting can be advantageously used.
32. Describe the process of extrusion. Why is it used?
33. What is Lautal metal? Where is it used?
34. What does the trade name "HIDUMINIUM" mean? Where is it principally used?
35. What does the term "strip steel" construction mean?
36. Describe some of the advantages of strip steel in comparison to other forms of airplane construction.
37. What is the trend of future airplane construction in reference to materials?
38. Compare the use of steel and dural in aircraft structures. Which is more durable?
39. Why is strip steel not used in the U. S. A.?
40. Compare the weight of steel and dural.

CHAPTER III

41. Why is accuracy important when working metal airplane structures?
42. What is meant by the limitation of light structures?
43. Describe stretcher leveled sheets. Why are they used?
44. What is crinkling? What is elasticity?
45. What is meant by the term "shell structure"?
46. In the process of fabrication of dural, what is the important fact to remember in reference to workability?
47. Describe the various groups of alloys and their workability.
48. What is a shear? Describe the process of shearing.
49. What is meant by "punching"? Where is it used?
50. What limitations are applied to punching when it is used with dural sheets?
51. What are the advantages of punching, and why is it done?
52. Name some methods of cutting up material.
53. Define the term "brake work".
54. Describe the fundamental principles and function of a power or hand brake. Describe the various types.
55. What are localized stresses?
56. Why is the material lubricated in bending and forming?
57. Why are sharp radii avoided in production?
58. What is metal grain?
59. Describe the technique of drilling.
60. Describe the various kinds of drill shanks.
61. What is the action of twist drill in flat sheet stock of light gauge?
62. Describe pressing and forming. What are the advantages when used in quantity production?
63. Name some parts that are pressed.

64. What is a hydraulic press?
65. What is meant by the terms: clearing, stretching, die cast, die forming, cold working, hot working, aging, sheet stock.
66. What is spinning? How is it performed?
67. What parts are spun?
68. What is rolling? Describe the machine.
69. What does rolling do to the material?
70. How is corrugating accomplished? Name its advantages.
71. Why is corrugated stock not used in modern design for exterior covering?
72. Describe the process of skinning.
73. What is a skinning jig or frame? Name the function.
74. What is preformed material?
75. What do we mean by nose profiles, stretching, springing?
76. How is a metal wing covered?
77. How is a metal fuselage covered?
78. What sizes of sheets are used, if possible?
79. What is meant by uniformity, interchangeability, and standardization of parts?
80. Why are pattern mockups used?
81. What is a pattern mockup usually made of?
82. Describe the purpose and function of the mockup.
83. What are the requirements in bending and forming?
84. What is meant by a tool edge radius?
85. Give the empirical formula for bending allowance.
86. Define what is meant by the minimum possible bending radius.
87. Why are lightening holes staggered? Why are they used?
88. Why are lightening holes circular?
89. Why is quantity production profitable?
90. Why are circular airplane parts easy to produce?
91. Name some of the basic elementary structural sections commonly used in airplane structures.
92. What is bumping? What is a power hammer?
93. What is a wooden former? Why used?
94. What does alteration of the physical characteristics do to metal sheets?
95. What does cold working do to the hardness of dural?
96. What is metal fracture?
97. What does the term "annealing" mean?
98. What is crystallization?
99. Describe a riveted joint. Why is riveting used?
100. What does the efficiency of a riveted joint mean? How is it determined?
101. Give the definition of the term "rivet shear".
102. What is the meaning of the term "rivet pitch"?
103. What is a tension member? What is a compression member?
104. What is the grip of a rivet?
105. Describe cold rivet driving. What size of shank diameter of the rivet is the largest size suitably used for cold driving?

106. What is hot driving? Give the sizes of rivet shanks used in this process.
107. What determines the shank diameter of a rivet?
108. What is meant by clinching? Heading over?
109. What material is used for rivets?
110. What determines the edge distance?
111. Why are rivet holes reamed?
112. How is hand riveting accomplished?
113. What is meant by the term "shank pressure"?
114. Describe a squeeze riveter. How is it operated?
115. What limits the use of the squeeze riveter?
116. Why are rivets squeezed?
117. What is the yoke. throat clearance, heading over die?
118. Describe the process of "bucking up". What is a "buckerup"?
119. Describe a pneumatic riveter.
120. Why are not rivets hand driven? What is a rivet set?
121. What is a single shot riveter? Why is it used? Describe the fundamental principles of the single shot riveter.
122. Describe a dimpled joint.
123. What material is used for a soft rivet? Hard rivet?
124. What is the maximum shank diameter for squeeze riveting?
125. Describe various kinds of squeeze riveters.
126. How are rivets preserved for working after heat treatment?
127. Name the common types of rivets.
128. What is rivet spinning? Why is its use limited?
129. What is a pin joint? Why is the use of hollow rivets limited?
130. What determines rivet shank driving pressures?
131. Describe the machining characteristics of dural.
132. What precautions are necessary to tapping and threading dural nuts, bolts, etc.?
133. What is anodic treatment and its function?
134. Name some other plating processes.
135. What is beading? Where used?
136. From what basic elementary structural sections are most airplane spars derivations of?
137. What constitutes a simple spar?
138. Describe the purpose and the function of a bulkhead.
139. Describe a simple bulkhead.
140. Describe simple strut end joints.
141. What are the requirements for a simple bulkhead? Describe the manufacture of the same.
142. What influences the design of a bulkhead?
143. What is a stiffener? What is its purpose?
144. What is fusion welding? How is it done? What are the limitations of fusion welding? What is resistance welding? How is it done? What are its limitations?
145. Why are fluxing agents used? Describe a fluxing agent.
146. What subsidiary parts of the structure are welded?
147. Describe the fundamental differences of spot,arc, and shot welding.
148. What material are the electrodes made out of?

149. What material is capable of being "spot" welded?
150. What material can be "shot" welded?
151. What is a nibbling machine?
152. Name some secondary production tools.
153. What are the following hand tools used for: Dolly bar, rubber hammer, stakes, beam trammels, micrometer, Schleroscope?
154. Describe the Junkers system of inside riveting.
155. Why is inside riveting used? Is it used in the U. S. A.?
156. Name some of the types of tools used in inside riveting?
157. What is an eccentric dolly or eccentric die?
158. What is a draw bench? What is a roller die?
159. Describe the process of strip steel forming.
160. Compare the production advantages of metal and wooden aircraft structures. What type of labor is required? Skilled or semi-skilled?
161. Which costs the most initially to undertake production: Wood, metal, or strip steel composite construction?
162. Name the various crafts involved in the production of the metal structure of an airplane?
163. What percentage of operations are hand formed? What percentage are machine formed?
164. What is meant by a "gang" drill, gang punch, etc.?
165. What is meant by a male die? A female die?
166. Why are riveting tools operated by compressed air?

CHAPTER IV

167. What is meant by the weight to strength ratio?
168. What is the limitation of a standard rolled section?
169. Why are joints undesirable?
170. How is a section rolled?
171. What is the limiting thickness for extrusions?
172. What is the advantages of a built-up structural shape?
173. What system of securing together is used in built-up shapes?
174. Why is a built-up section more expensive than an extrusion?
175. Name some basic extruded shapes?
176. What is a subsidiary member?

CHAPTER V

177. Describe the fundamental differences between a monocoque, semi-monocoque a welded tubular structure, and a riveted frame structure.
178. Give reasons as to which may cost the most in production.
179. What are the limitations imposed on the production of the metal shell fuselage?
180. What does the term "metal shell" mean? Describe some current types of metal shell fuselages.
181. Describe the ring bulkhead construction of the following: Northrop, Boeing, Clark, Douglas, Martin Clipper, Vultee.

182. Why are metal sheets laminated?
183. What is a point of localized stress?
184. How are the bulkheads secured to the structure?
185. Describe a semi-monocoque structure.
186. How is fabric attached to a riveted frame structure?
187. Why are riveted frame fuselages used?
188. Describe a wrap fitting. What are they usually made of?
189. Describe a welded steel tubing fuselage.
190. Describe the structural elements of a rolled strip steel fuselage.
191. Describe the two ways to brace frame fuselages.
192. What is a gusset?
193. Why is joint construction important?
194. How are joints made in the following: Welded steel tubing fuselage, riveted frame fuselage, rolled strip fuselage?
195. What is a fire wall? How are they built?
196. What material is used for fire walls? How does the fire wall protect the personnel?
197. Which is the lightest for similar structures: The shell structure, the welded steel tubing structure, or the riveted frame dural and fabric structure? Which is the most expensive?
198. What kind of riveting tools are used to rivet the shell plating?

CHAPTER VI

199. What is a rib and its function?
200. Describe some typical American metal ribs.
201. Describe (1) Junkers wing. (2) Thaden wing. (3) Ford wing. (4) Boeing wing.
202. What is a multicellular wing, and why is it used?
203. What is a multiple spar wing, and why is it used?
204. Describe the wing of a Martin Clipper.
205. What is the construction of a Northrop wing?
206. How is a Vultee wing built?
207. How are strip steel ribs held together?
208. Compare various contemporaneous wing structures.
209. How is the metal skin held to the internal structure?
210. Why is flush riveting necessary for exposed surfaces?
211. What is meant by the term "stressed skin"?
212. How is the covering strengthened?
213. Why must a strong nose section with a heavy gauge be used on wing and horizontal tail surfaces in the area of the propeller strip stream?
214. How does the weight of a metal wing compare to that of other wings per square foot? Compare the costs as well.
215. Why are fabric control surfaces sometimes used with a metal wing?
216. Why is an inner corrugated skin sometimes used?
217. Describe various types of metal control surfaces.
218. What is a rib jig?
219. How are tapered rib blanks manufactured?
220. What is a nettle fold?

221. What kind of tools are used to rivet the wing skin?
222. Give some basic elementary spar shapes.
223. What is a web member, stiffener, shear member, flange?
224. Describe a typical spar.
225. How are metal spars fabricated?
226. Describe a Junkers spar. A Ford spar. A Grumman spar.
227. What is a Box Spar, an "I" beam? Give typical examples.
228. Define the height to width relation requirements.
229. What are subsidiary structures?
230. Describe some rolled strip steel riveted spars.
231. What is torsion?
232. What determines stiffener spacing?
233. Why are webs usually made of light gauge material?
234. Give various examples of spar forms.
235. What is meant by eccentricity?
236. What is a plate girder?
237. Describe welded steel spar construction.
238. Describe a "shot welded" steel spar.
239. What is the function of a diagonal web member?
240. Why are channel sections used frequently for flanges?
241. Why are corrugated webs frequently used?
242. Why are webs deformed into various shapes?
243. How are webs stiffened without excess weight being added?
244. Why are flanges sometimes made in multiple layers?
245. How are drag struts usually attached?
246. What is meant by deforming?
247. What does "monospar" mean?
248. Which kind of spars are economical to produce in production?
249. How is flanging executed, and what machine is used?
250. Which is more resistant to bending, a straight web or a corrugated web if the gauges are equivalent?
251. What is the function of a spacer on the webs?
252. How does the efficiency of long pin rivets compare to short grip rivets in holding material?
253. What is hemming?
254. What is the function of a gusset plate?
255. Why are shear members diagonally arranged in built up spars?
256. What gauge material is used for the webs, the flanges, the stiffeners? Give some typical examples.
257. Why are box spars used in preference to "I" beams, and vice versa?
258. How is a spar braced laterally against lateral flexure?
259. How is a spar braced to resist bending in the vertical aspect?

CHAPTER VII

260. Describe the construction of various tail areas.
261. Which is the best; all metal shell type, or metal frame and fabric? When and where is each used and why?
262. How are control areas covered?
263. What method is used to hold the skin to the internal framework?

264. Why are tail areas sometimes corrugated or stiffened on the outside?
265. How are internal structures built up?
266. Why are straight lines sometimes used?
267. Why are small aspect ratios sometimes used?
268. What spar sections are ordinarily used in control areas?
269. How do metal control areas compare in weight to wooden structures?

CHAPTER VIII

270. What is a metal longeron?
271. What is a metal fairing and a fillet? How are they made?
272. Describe economical production methods in the manufacture of bulkheads.
273. How are cowls made?
274. What is a flat pattern?
275. What is cabin flooring usually made of?
276. Describe a Junkers spar joint.
277. What is a stay bolt, and why are they used?
278. What are fuel tanks made of? How are they made?
279. What is the function of a baffle plate?
280. How is a fuel tank strengthened?
281. How are they mounted in a plane?
282. What gauge material is usually used?
283. What means of jointing is usually employed?
284. How does the weight of a system of multiple tanks compare with a single large tank?
285. What shape is the best for metal fuel tanks?

CHAPTER IX

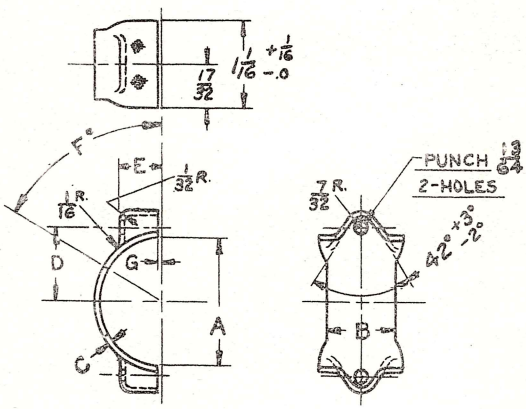
286. Enumerate the various problems encountered in servicing, and their relation to the design and fabrication of metal aircraft and the component parts thereof.
287. What are servicing costs, and how do they affect the initial investment?
288. What advantages are attached to interchangeability, standardization, and rapid installation of parts?
289. What are the disadvantages of "handed" parts?
290. Describe the process of repairing a metal wing in comparison to a wooden wing, or a wing covered with fabric over a metal frame.
291. Describe what parts of a metal plane are subject to damage in the ordinary routine of handling on the ground.
292. What is considered a major repair? A minor repair?
293. What is fatigue?
294. Why do most air lines prefer all metal equipment?
295. Considering the initial and servicing costs of the present time, would you consider the all metal plane a good investment for the private buyer of limited means?
296. How does inspection on metal structures compare with that of other types of construction?

297. Which type of plane is more easily damaged under ordinary service ground routine?
298. What type is the most expensive to repair?
299. Make a comparison of the tools required to repair each type in a repair depot.

CHAPTER X

300. Why is weight control necessary?
301. Name the "number prefixes" for steel tubing for airplane structures ordinarily used.
302. What is mild carbon steel? What does 1025 steel mean?
303. What is chrome molybdenum and nickel steel?
304. What agencies usually determine the specifications for the guidance of manufacturers in producing materials?
305. Name the various alloy temper designations.
306. Give the strength of the dural alloys.
307. What are the various kinds of steel and aluminum or dural tubing available?
308. What gauges of sheet stock are usually available?
309. What is a Parker screw, and what are they used for?
310. What material are aircraft bolts made from?
311. What is the bearing strength of sheet stock?
312. What gauge is used for plate gauges?

AERO SUPPLY MANUFACTURING CORP.
CORRY, PA.



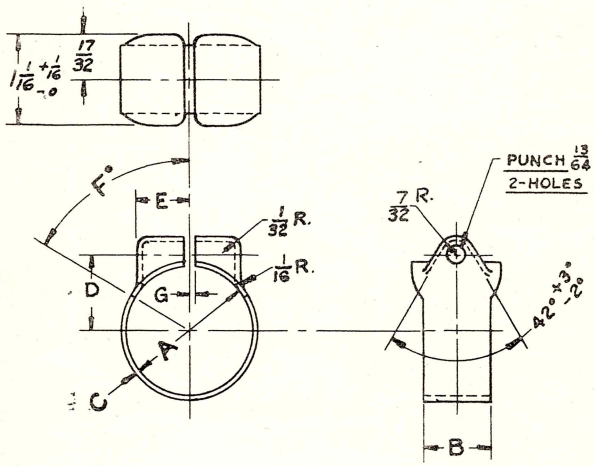
DASH NOS.	A	B	C	D	E	F°	G
T8	1/2	1 1/16	.037	3/8	.287		1/16
T10	5/8	1 1/16	.037	7/16	.349		1/16
T12	3/4	1 1/16	.037	1/2	.412		1/16
T14	7/8	1 1/16	.037	9/16	13/32		1/16
T16	1	1 1/16	.037	41/64	7/16		1/16
T18	1 1/8	1 1/16	.037	45/64	15/32		1/16
T20	1 1/4	1 1/16	.037	49/64	1/2		1/8
T22	1 3/8	1 1/16	.037	53/64	17/32		1/8
T24	1 1/2	7/8	.037	57/64	9/16	64°-00'	1/8
T26	1 5/8	7/8	.050	61/64	19/32	60°-00'	1/8
T28	1 3/4	1	.050	1 1/32	5/8	58°-15'	1/8
T30	1 7/8	1	.050	1 3/32	21/32	55°-45'	3/16
T32	2	1	.050	1 5/32	11/16	54°-30'	3/16
T34	2 1/8	1	.050	1 7/32	23/32	53°-15'	3/16
T36	2 1/4	1	.050	1 9/32	3/4	52°-15'	3/16

STEEL CADMIUM PLATED.

CLAMP – TWO BOLT TUBE

PLATE 1

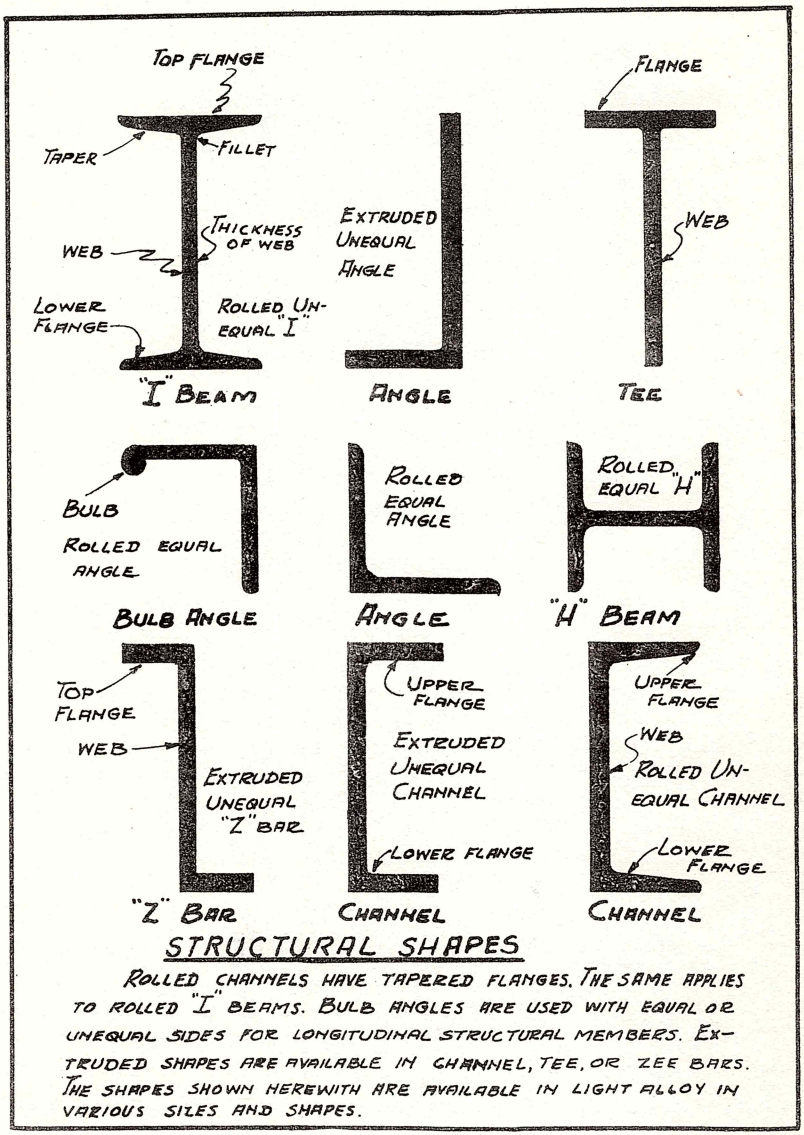
AERO SUPPLY MANUFACTURING CORP.
CORRY, PA.



DASH NOS.	A	B	C	D	E	F°	G
8	1/2	1 1/16	.037	3/8	.287		1/16
10	5/8	1 1/16	.037	7/16	.349		1/16
12	3/4	1 1/16	.037	1/2	.412		1/16
14	7/8	7/8	.037	9/16	13/32	89°-00'	1/16
16	1	7/8	.037	41/64	7/16	81°-30'	1/16
18	1 1/8	7/8	.037	45/64	15/32	75°-30'	1/16
20	1 1/4	7/8	.037	49/64	1/2	71°-00'	1/8
22	1 3/8	7/8	.037	53/64	17/32	67°-00'	1/8
24	1 1/2	7/8	.037	57/64	9/16	64°-00'	1/8
26	1 5/8	7/8	.050	61/64	19/32	60°-00'	1/8
28	1 3/4	1	.050	1 1/32	5/8	58°-15'	1/8
30	1 7/8	1	.050	1 3/32	21/32	55°-45'	3/16
32	2	1	.050	1 5/32	11/16	54°-30'	3/16
34	2 1/8	1	.050	1 7/32	23/32	53°-15'	3/16
36	2 1/4	1	.050	1 9/32	3/4	52°-15'	3/16

STEEL CADMIUM PLATED. CLAMPS - SINGLE BOLT TUBE.

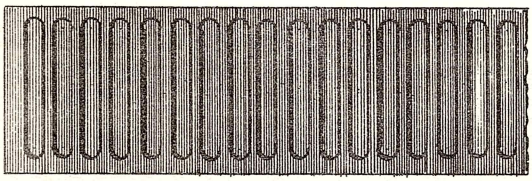
PLATE 2



STRUCTURAL SHAPES

ROLLED CHANNELS HAVE TAPERED FLANGES. THE SAME APPLIES TO ROLLED "I" BEAMS. BULB ANGLES ARE USED WITH EQUAL OR UNEQUAL SIDES FOR LONGITUDINAL STRUCTURAL MEMBERS. EXTRUDED SHAPES ARE AVAILABLE IN CHANNEL, TEE, OR ZEE BARS. THE SHAPES SHOWN HEREWITH ARE AVAILABLE IN LIGHT ALLOY IN VARIOUS SIZES AND SHAPES.

PLATE 3



TYPICAL EXAMPLE OF STIFFENED FLAT SHEET

SHEETS FOR SPAR MEMBERS, WEBS, ETC. ARE FABRICATED FROM SWAGED SHEET MATERIAL. THE WORK IS DONE BY PRESSING OUT FLAT MATERIAL. WEB MEMBERS CAN BE RIVETED TO FLAT MEMBERS MORE EASILY THAN CORRUGATED SHEETS WITH DEFORMATIONS CLEARED IN BOX SPAR TYPES. DEPTH OF SWAGING IS DEPENDENT ON THE GAUGE AND PITCH OF DEFORMATIONS. THE DEFORMATIONS ACT SAME AS A STIFFENER.

CORRUGATED SHEETS

BY CORRUGATING AN EQUAL DISPOSITION OF THE MATERIAL ON EACH SIDE OF THE NEUTRAL AXIS ENABLES A GREATER RESISTANCE TO LATERAL BENDING. THE CORRUGATIONS INCREASE STRENGTH IN SHEAR FOR THE SAME REASONS. FOR SAME AREA A CORRUGATED SHEET WEIGHS ABOUT ONE THIRD MORE. IN BENDING THE CORRUGATIONS ACT AS A SERIES OF SHORT COLUMNS IN SHEAR AND A SERIES OF TUBES WHEN SUBJECT TO LATERAL BENDING. CORRUGATED SHEETS ARE USED AS AN INNER STIFFENER AND RIVETED TO A SMOOTH OUTER SKIN TO INCREASE THE RESISTANCE TO BENDING.

"A" "B"

IN "A" A HALF CIRCULAR STIFFENER IS SHOWN RIVETED TO A RIB WEB. IN "B" THE WEB IS DEFORMED BY PRESSING TO ACCOMPLISH THE SAME PURPOSE. "A" IS HEAVIER THOUGH STRONGER. "B" IS LIGHTER AND LESS COSTLY. THE RESISTANCE TO LATERAL BENDING IN "B" IS PRACTICALLY THE SAME AS "A." IN PRODUCTION "B" IS MORE DESIREABLE.

PLATE 4

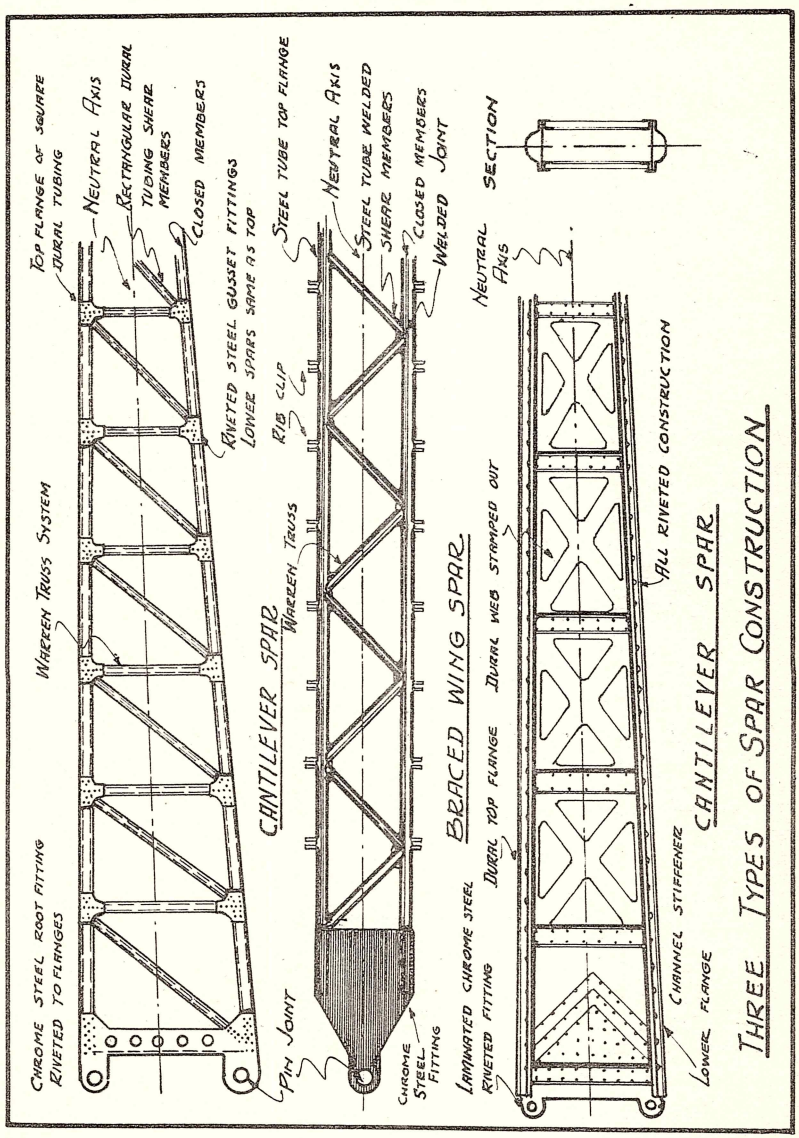
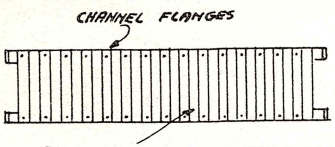
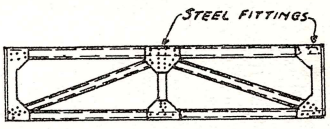
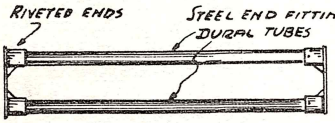
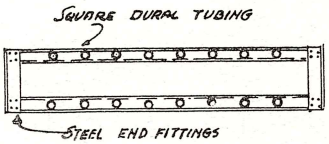

CHROME STEEL ROOT FITTING RIVETED TO FLANGES
WARREN TRUSS SYSTEM
TOP FLANGE OF SQUARE DURAL TUBING
NEUTRAL AXIS
RECTANGULAR DURAL TUBING SHEAR MEMBERS
CLOSED MEMBERS
RIVETED STEEL GUSSET FITTINGS
LOWER SPARS SAME AS TOP
CANTILEVER SPAR
PIN JOINT
WARREN TRUSS
RIB CLIP
STEEL TUBE TOP FLANGE
NEUTRAL AXIS
STEEL TUBE WELDED SHEAR MEMBERS
CLOSED MEMBERS WELDED JOINT
CHROME STEEL FITTING
BRACED WING SPAR
LAMINATED CHROME STEEL RIVETED FITTING
DURAL TOP FLANGE
DURAL WEB STAMPED OUT
NEUTRAL AXIS
SECTION
ALL RIVETED CONSTRUCTION
CHANNEL STIFFENER
LOWER FLANGE
CANTILEVER SPAR
THREE TYPES OF SPAR CONSTRUCTION

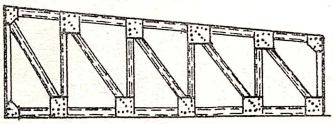
PLATE 5

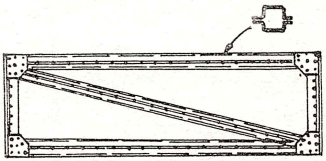


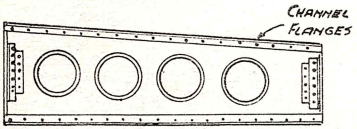




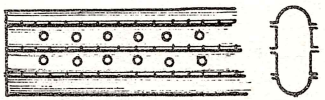


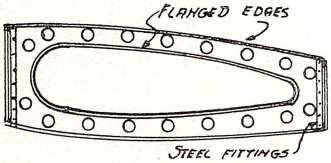

PROFILE DRAG STRUT SQUARE DURAL TUBING WITH STEEL FITTINGS

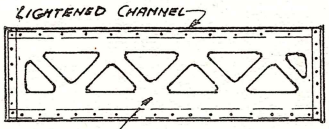

STEEL END FITTINGS - DURAL TUBES WITH RIVETED FLANGES



BOX SPAR PROFILE DRAG STRUT STEEL FITTINGS - DURAL FLANGES AND WEB


ROLLED STEEL RIVETED DRAG STRUT SPECIAL FITTINGS USED FOR JOINT & SPAR ATTACHMENT





DURAL WEB - DURAL FLANGES - STEEL FITTINGS ALL RIVETED.

DRAG STRUTS MAY BE OF STRAIGHT TYPE OR OF THE PROFILE TYPE. IN A 2 SPAR FABRIC COVERED WING THEY ARE CROSS WIRE BRACED. IN METAL WINGS THE DRAG STRUTS ARE AUXILIARY STIFFENERS TO WING IN TORSION ACTING IN CONJUNCTION WITH WINGS. THE DRAG STRUT MUST BE STRONG TO FORCES IN BENDING AND TORSION. THE USUAL METAL SPAR SECTIONS ARE SOMETIMES USED. THE FORMS SHOWN ABOVE ARE TYPICAL.

PLATE 6

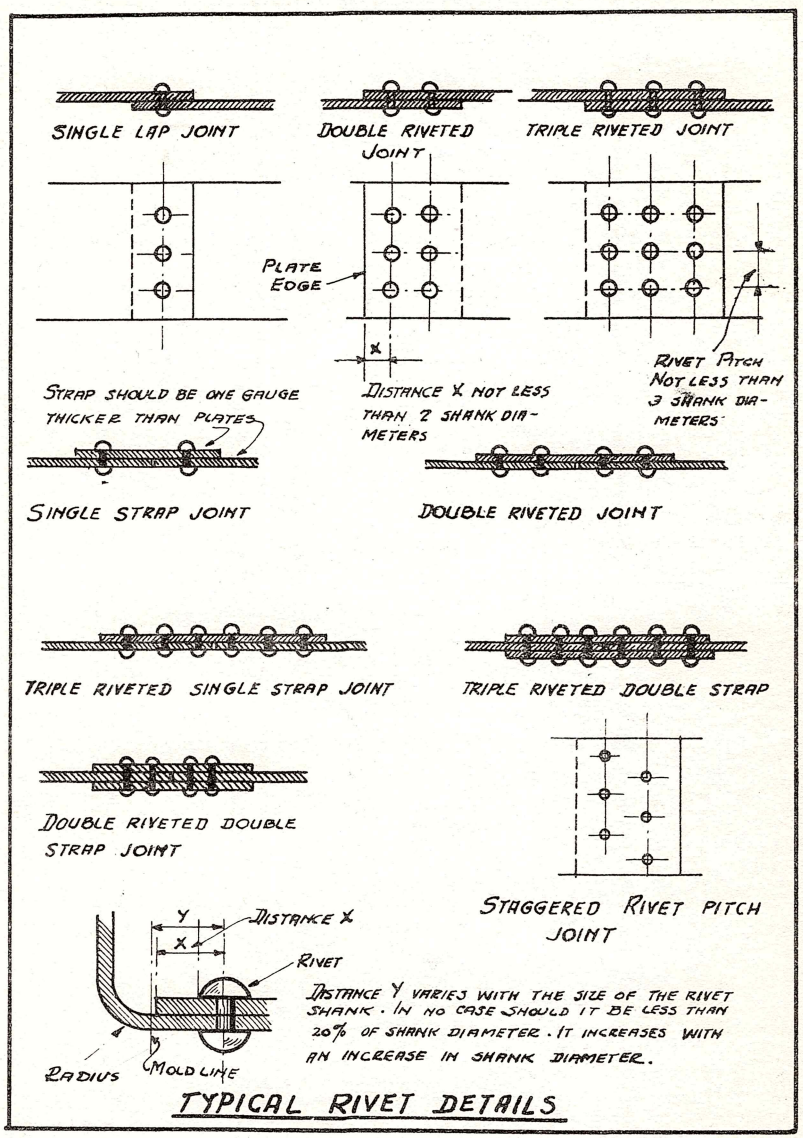

SINGLE LAP JOINT
DOUBLE RIVETED JOINT
TRIPLE RIVETED JOINT
PLATE EDGE
X
RIVET PITCH NOT LESS THAN 3 SHANK DIAMETERS
STRAP SHOULD BE ONE GAUGE THICKER THAN PLATES
DISTANCE X NOT LESS THAN 2 SHANK DIAMETERS
SINGLE STRAP JOINT
DOUBLE RIVETED JOINT
TRIPLE RIVETED SINGLE STRAP JOINT
TRIPLE RIVETED DOUBLE STRAP
DOUBLE RIVETED DOUBLE STRAP JOINT
STAGGERED RIVET PITCH JOINT
Y
X
DISTANCE X
RIVET
DISTANCE Y VARIES WITH THE SIZE OF THE RIVET SHANK. IN NO CASE SHOULD IT BE LESS THAN 20% OF SHANK DIAMETER. IT INCREASES WITH AN INCREASE IN SHANK DIAMETER.
RADIUS
MOLD LINE
TYPICAL RIVET DETAILS

PLATE 7

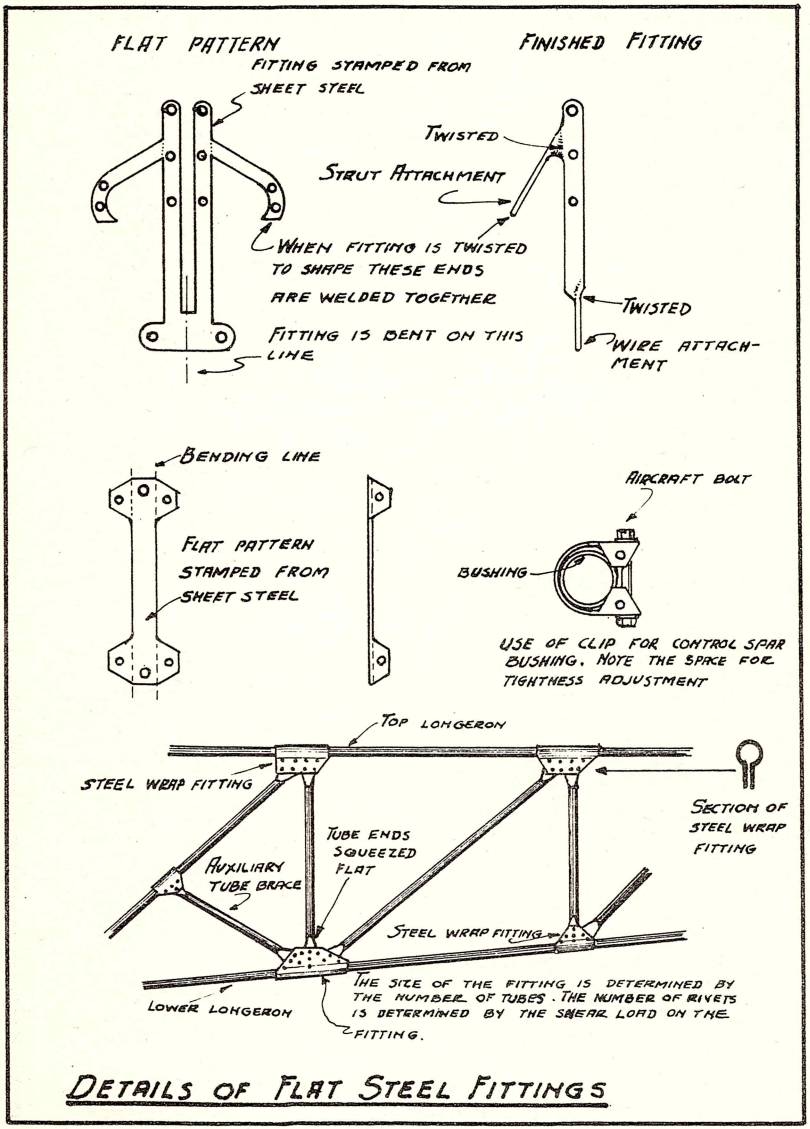
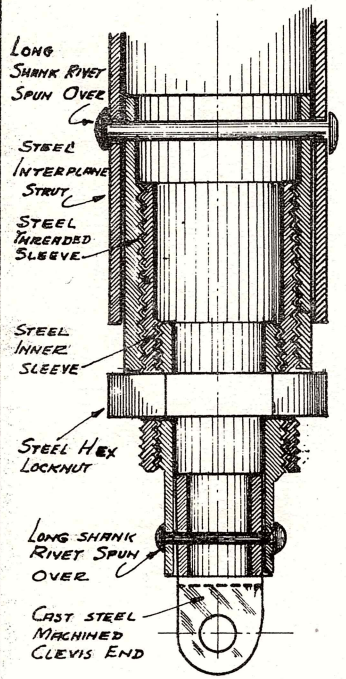
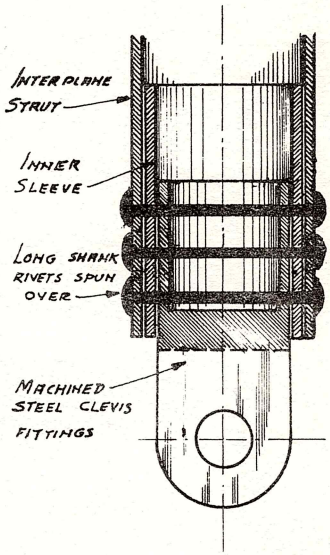

FLAT PATTERN
FINISHED FITTING
FITTING STAMPED FROM SHEET STEEL
TWISTED
STRUT ATTACHMENT
WHEN FITTING IS TWISTED TO SHAPE THESE ENDS ARE WELDED TOGETHER
TWISTED
FITTING IS BENT ON THIS LINE
WIRE ATTACHMENT
BENDING LINE
FLAT PATTERN STAMPED FROM SHEET STEEL
AIRCRAFT BOLT
BUSHING
USE OF CLIP FOR CONTROL SPAR BUSHING. NOTE THE SPACE FOR TIGHTNESS ADJUSTMENT
TOP LONGERON
STEEL WRAP FITTING
SECTION OF STEEL WRAP FITTING
TUBE ENDS SQUEEZED FLAT
AUXILIARY TUBE BRACE
STEEL WRAP FITTING
THE SIZE OF THE FITTING IS DETERMINED BY THE NUMBER OF TUBES. THE NUMBER OF RIVETS IS DETERMINED BY THE SHEAR LOAD ON THE FITTING.
LOWER LONGERON
DETAILS OF FLAT STEEL FITTINGS

PLATE 8





ADJUSTABLE FIXED

EXAMPLES OF TUBULAR STRUT ENDS

STRUT ENDS MUST BE REINFORCED TO DISTRIBUTE END LOADS OVER AS LARGE AN AREA POSSIBLE. SHORT LENGTHS OF TUBING USED AS SLEEVES ACCOMPLISH THIS PURPOSE. THE BEARING AREA IS LIKEWISE INCREASED. THE END LOAD DETERMINES THE NUMBER OF RIVETS TO BE USED TO ATTACH THE CLEVIS FITTING. EACH RIVET CARRIES SO MUCH STRENGTH IN SHEAR. THE NUMBER IS INCREASED TO THE SHEAR FORCE IMPOSED BY THE END LOAD, WOULD REQUIRE FOR SAFETY.

PLATE 9

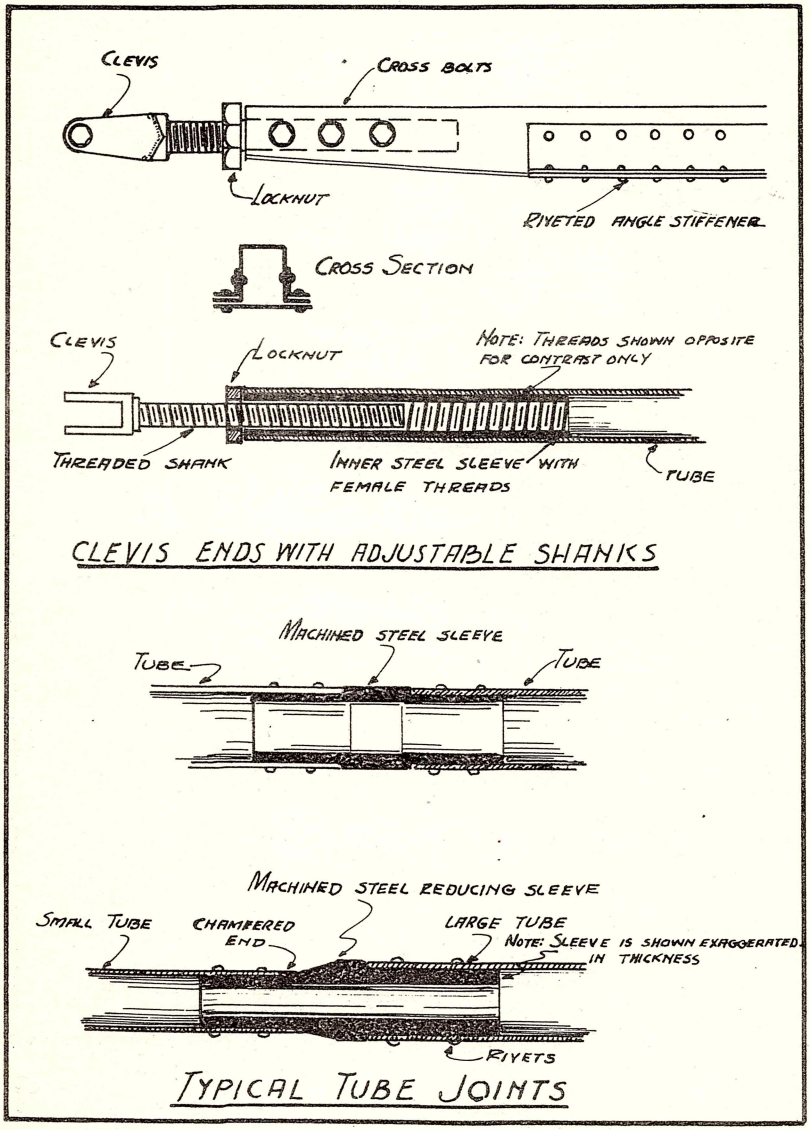
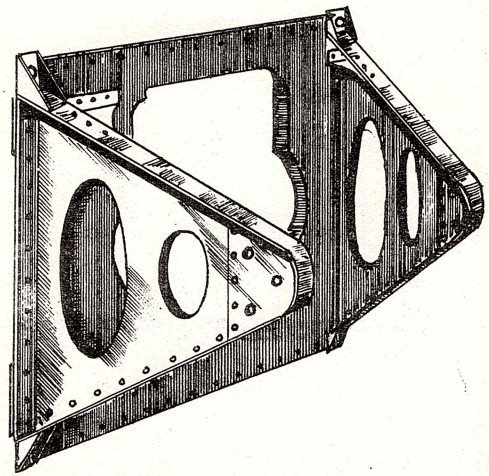
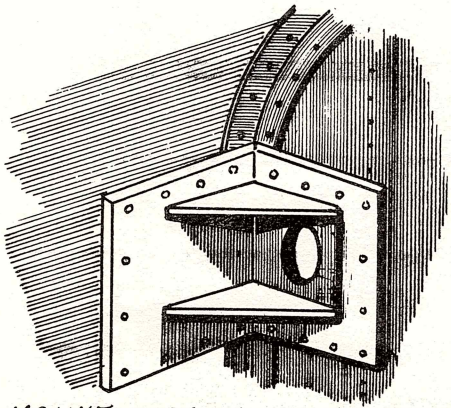

CLEVIS
CROSS BOLTS
LOCKNUT
RIVETED ANGLE STIFFENER
CROSS SECTION
CLEVIS
LOCKNUT
NOTE: THREADS SHOWN OPPOSITE FOR CONTRAST ONLY
THREADED SHANK
INNER STEEL SLEEVE WITH FEMALE THREADS
TUBE
CLEVIS ENDS WITH ADJUSTABLE SHANKS
MACHINED STEEL SLEEVE
TUBE
TUBE
MACHINED STEEL REDUCING SLEEVE
SMALL TUBE
CHAMFERED END
LARGE TUBE
NOTE: SLEEVE IS SHOWN EXAGGERATED IN THICKNESS
RIVETS
TYPICAL TUBE JOINTS

PLATE 10



SHEET METAL 3 CYLINDER AIRCOOLED ENGINE MOUNT



ENGINE MOUNT CASTING ON FIREWALL BULKHEAD

PLATE 11

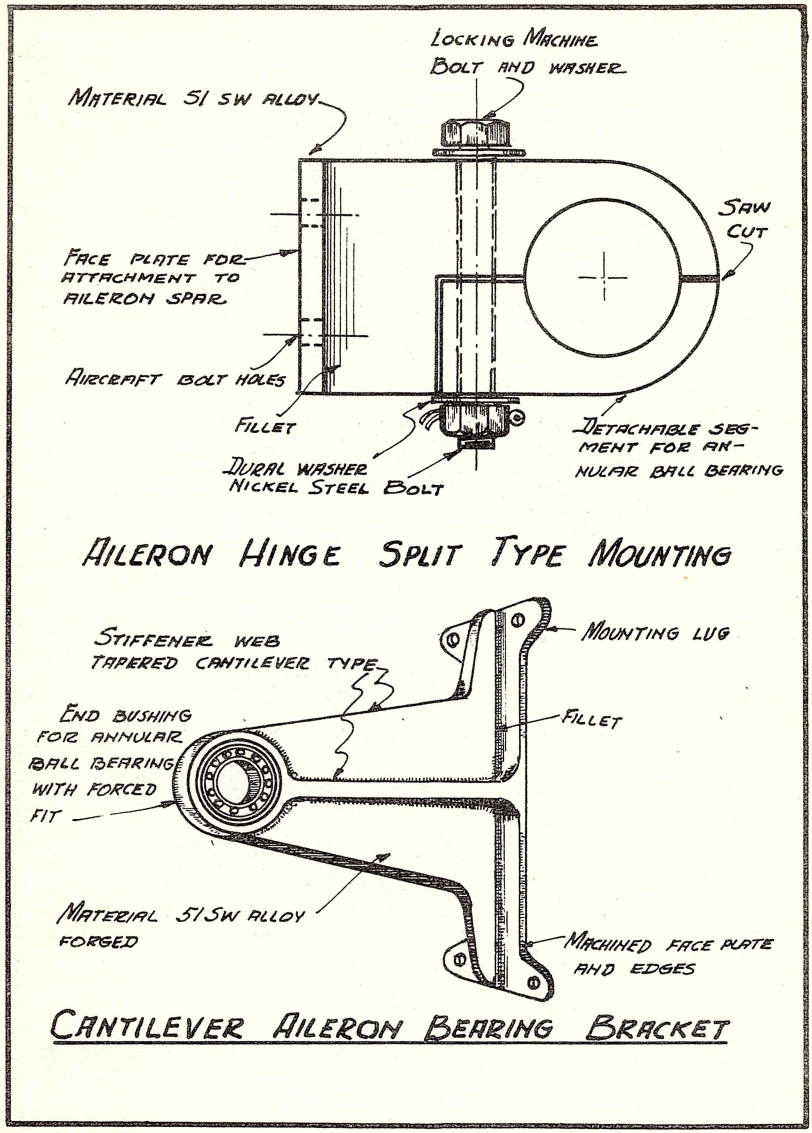

LOCKING MACHINE BOLT AND WASHER
MATERIAL 51 SW ALLOY
SAW CUT
FACE PLATE FOR ATTACHMENT TO AILERON SPAR
AIRCRAFT BOLT HOLES
FILLET
DETACHABLE SEGMENT FOR ANNULAR BALL BEARING
DURAL WASHER
NICKEL STEEL BOLT
AILERON HINGE SPLIT TYPE MOUNTING
STIFFENER WEB TAPERED CANTILEVER TYPE
MOUNTING LUG
END BUSHING FOR ANNULAR BALL BEARING WITH FORCED FIT
FILLET
MATERIAL 51SW ALLOY FORGED
MACHINED FACE PLATE AND EDGES
CANTILEVER AILERON BEARING BRACKET

PLATE 12

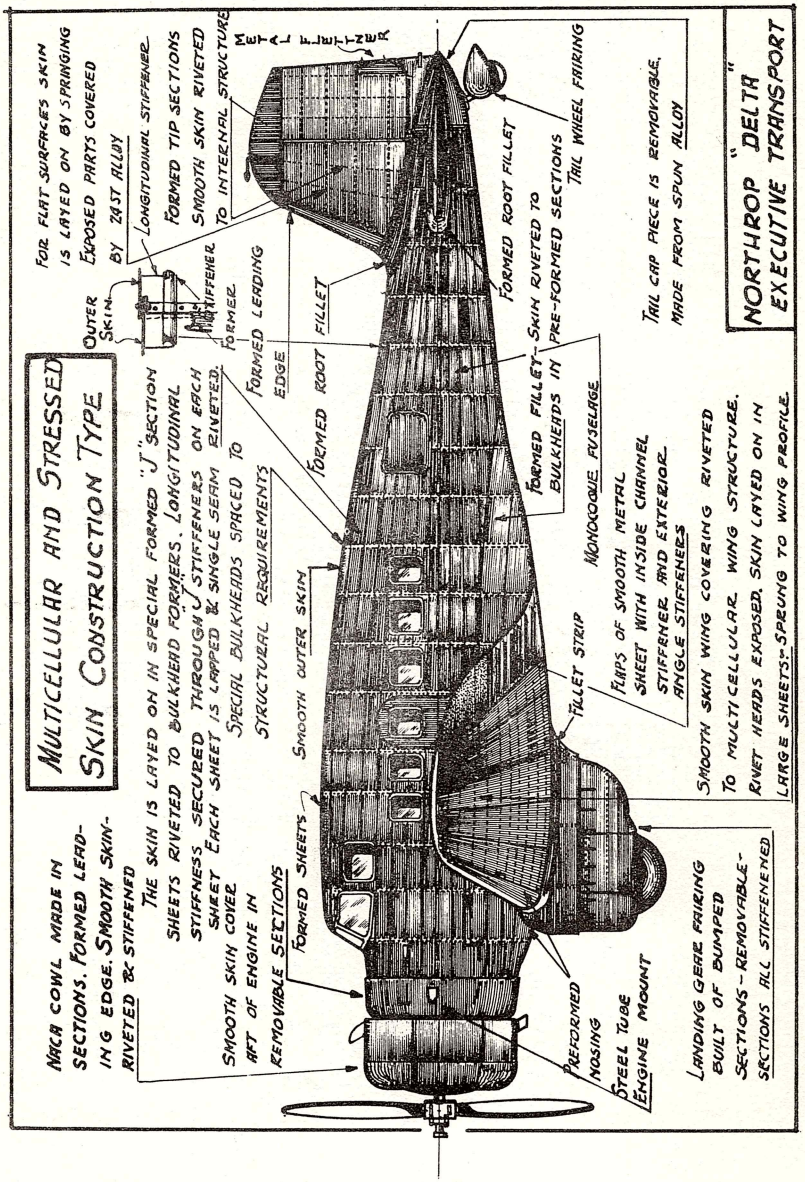

MULTICELLULAR AND STRESSED SKIN CONSTRUCTION TYPE
NACA COWL MADE IN SECTIONS. FORMED LEADING EDGE. SMOOTH SKIN-RIVETED & STIFFENED
THE SKIN IS LAYED ON IN SPECIAL FORMED "J" SECTION SHEETS RIVETED TO BULKHEAD FORMERS. LONGITUDINAL STIFFNESS SECURED THROUGH "J" STIFFENERS ON EACH SHEET. EACH SHEET IS LAPPED & SINGLE SEAM RIVETED.
SMOOTH SKIN COVER AFT OF ENGINE IN REMOVABLE SECTIONS
FORMED SHEETS
SMOOTH OUTER SKIN
SPECIAL BULKHEADS SPACED TO STRUCTURAL REQUIREMENTS
FORMED LEADING EDGE
FORMED ROOT FILLET
FILLET STRIP
MONOCOQUE FUSELAGE
FLAPS OF SMOOTH METAL SHEET WITH INSIDE CHANNEL STIFFENER AND EXTERIOR ANGLE STIFFENERS
SMOOTH SKIN WING COVERING RIVETED TO MULTI CELLULAR WING STRUCTURE. RIVET HEADS EXPOSED. SKIN LAYED ON IN LARGE SHEETS-SPRUNG TO WING PROFILE.
PREFORMED NOSING
STEEL TUBE ENGINE MOUNT
LANDING GEAR FAIRING BUILT OF BUMPED SECTIONS-REMOVABLE-SECTIONS ALL STIFFENED
OUTER SKIN
STIFFENER
FORMER
FOR FLAT SURFACES SKIN IS LAYED ON BY SPRINGING
EXPOSED PARTS COVERED BY 24ST ALLOY
LONGITUDINAL STIFFENER
FORMED TIP SECTIONS
SMOOTH SKIN RIVETED TO INTERNAL STRUCTURE
METAL FILLER
FORMED FILLET
SKIN RIVETED TO PRE-FORMED SECTIONS
TAIL WHEEL FAIRING
TAIL CAP PIECE IS REMOVABLE. MADE FROM SPUN ALLOY
NORTHROP "DELTA" EXECUTIVE TRANSPORT

PLATE 13

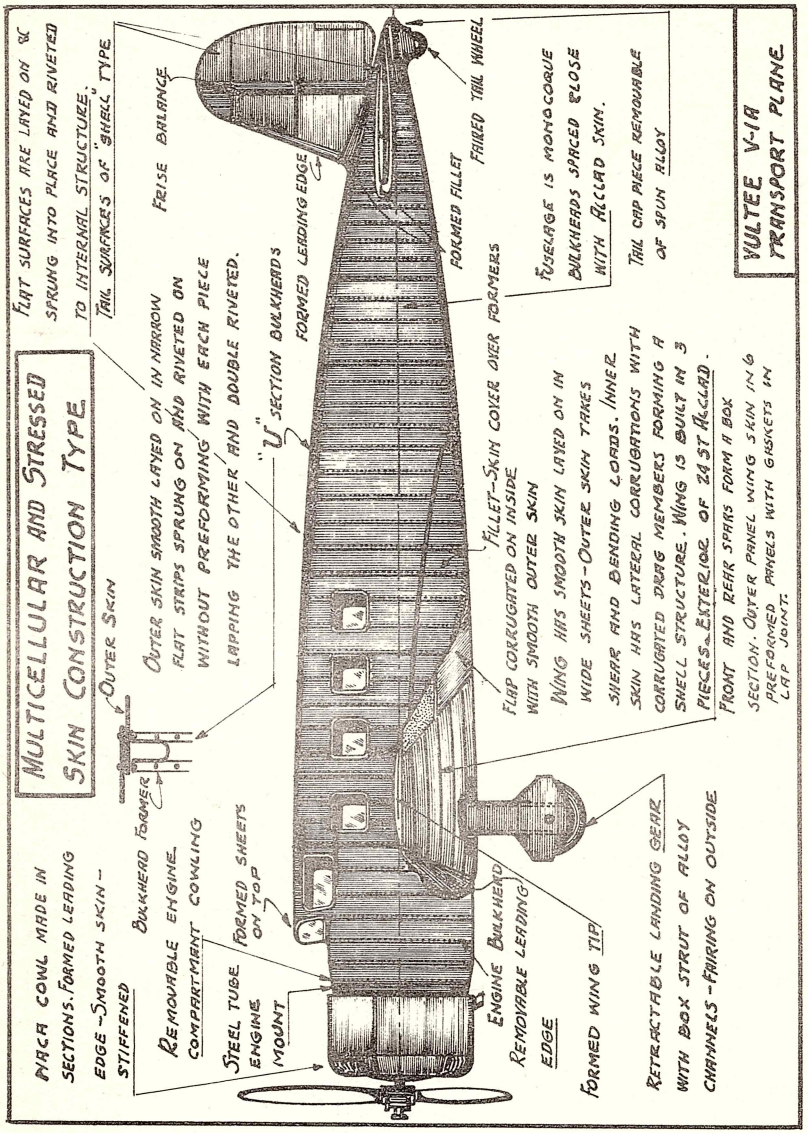

MULTICELLULAR AND STRESSED SKIN CONSTRUCTION TYPE
NACA COWL MADE IN SECTIONS. FORMED LEADING EDGE - SMOOTH SKIN - STIFFENED
REMOVABLE ENGINE COMPARTMENT COWLING
STEEL TUBE ENGINE MOUNT
FORMED SHEETS ON TOP
BULKHEAD FORMER
OUTER SKIN
OUTER SKIN SMOOTH LAYED ON IN NARROW FLAT STRIPS SPRUNG ON AND RIVETED ON WITHOUT PREFORMING WITH EACH PIECE LAPPING THE OTHER AND DOUBLE RIVETED.
"U" SECTION BULKHEADS FORMED LEADING EDGE
FLAT SURFACES ARE LAYED ON & SPRUNG INTO PLACE AND RIVETED TO INTERNAL STRUCTURE.
TAIL SURFACES OF "SHELL" TYPE
FRISE BALANCE
FAIRED TAIL WHEEL
FORMED FILLET
FILLET-SKIN COVER OVER FORMERS
FLAP CORRUGATED ON INSIDE WITH SMOOTH OUTER SKIN
WING HAS SMOOTH SKIN LAYED ON IN WIDE SHEETS - OUTER SKIN TAKES SHEAR AND BENDING LOADS. INNER SKIN HAS LATERAL CORRUGATIONS WITH CORRUGATED DRAG MEMBERS FORMING A SHELL STRUCTURE. WING IS BUILT IN 3 PIECES. EXTERIOR OF 24 ST ALCLAD.
FRONT AND REAR SPARS FORM A BOX SECTION. OUTER PANEL WING SKIN IN 6 PREFORMED PANELS WITH GASKETS IN LAP JOINT.
FUSELAGE IS MONOCOQUE BULKHEADS SPACED CLOSE WITH ALCLAD SKIN.
TAIL CAP PIECE REMOVABLE OF SPUN ALLOY
VULTEE V-1A TRANSPORT PLANE
ENGINE BULKHEAD
REMOVABLE LEADING EDGE
FORMED WING TIP
RETRACTABLE LANDING GEAR WITH BOX STRUT OF ALLOY CHANNELS - FAIRING ON OUTSIDE

PLATE 14

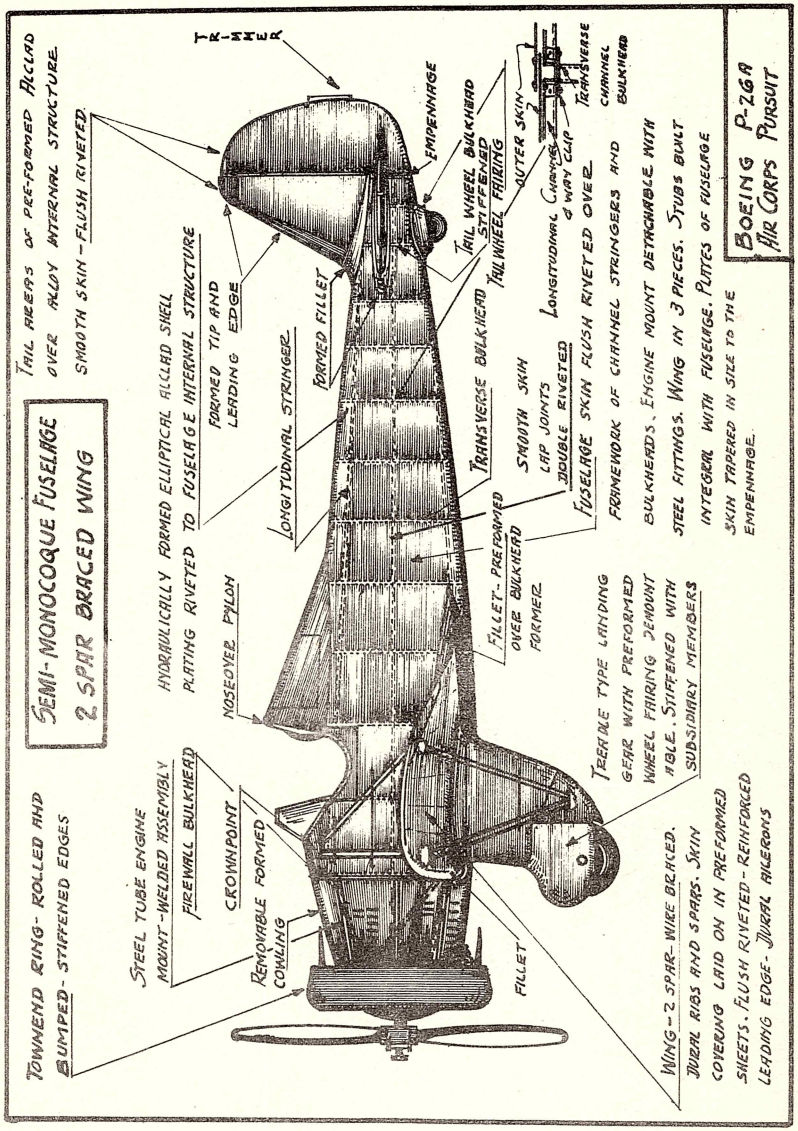

SEMI-MONOCOQUE FUSELAGE
2 SPAR BRACED WING
TAIL REEDS OF PRE-FORMED ALCLAD OVER ALOY INTERNAL STRUCTURE
SMOOTH SKIN - FLUSH RIVETED
TOWNEND RING - ROLLED AND DUMPED - STIFFENED EDGES
STEEL TUBE ENGINE MOUNT - WELDED ASSEMBLY
FIREWALL BULKHEAD
CROWNPOINT
REMOVABLE FORMED COWLING
HYDRAULICALLY FORMED ELLIPTICAL ALCLAD SHELL PLATING RIVETED TO FUSELAGE INTERNAL STRUCTURE
NOSEOVER PYLON
FORMED TIP AND LEADING EDGE
LONGITUDINAL STRINGER
FORMED FILLET
TRANSVERSE BULKHEAD
FILLET - PREFORMED OVER BULKHEAD FORMER
SMOOTH SKIN LAP JOINTS DOUBLE RIVETED
FUSELAGE SKIN FLUSH RIVETED OVER FRAMEWORK OF CHANNEL STRINGERS AND BULKHEADS. ENGINE MOUNT DETACHABLE WITH STEEL FITTINGS. WING IN 3 PIECES. STUBS BUILT INTEGRAL WITH FUSELAGE. BUTTS OF FUSELAGE SKIN TAPERED IN SIZE TO THE EMPENNAGE.
TRIPLE TYPE LANDING GEAR WITH PREFORMED WHEEL FAIRING PEDMOUNTABLE. STIFFENED WITH SUBSIDIARY MEMBERS
WING - 2 SPAR - WIRE BRACED. DUAL RIBS AND SPARS. SKIN COVERING LAID ON IN PREFORMED SHEETS. FLUSH RIVETED - REINFORCED LEADING EDGE - DUAL AILERONS
FILLET
TAIL WHEEL BULKHEAD
TAIL WHEEL FAIRING
OUTER SKIN
LONGITUDINAL CHANNEL
4 WAY CAP
TRANSVERSE CHANNEL BULKHEAD
EMPENNAGE
TRIMMER
BOEING P-26A
AIR CORPS PURSUIT

PLATE 15

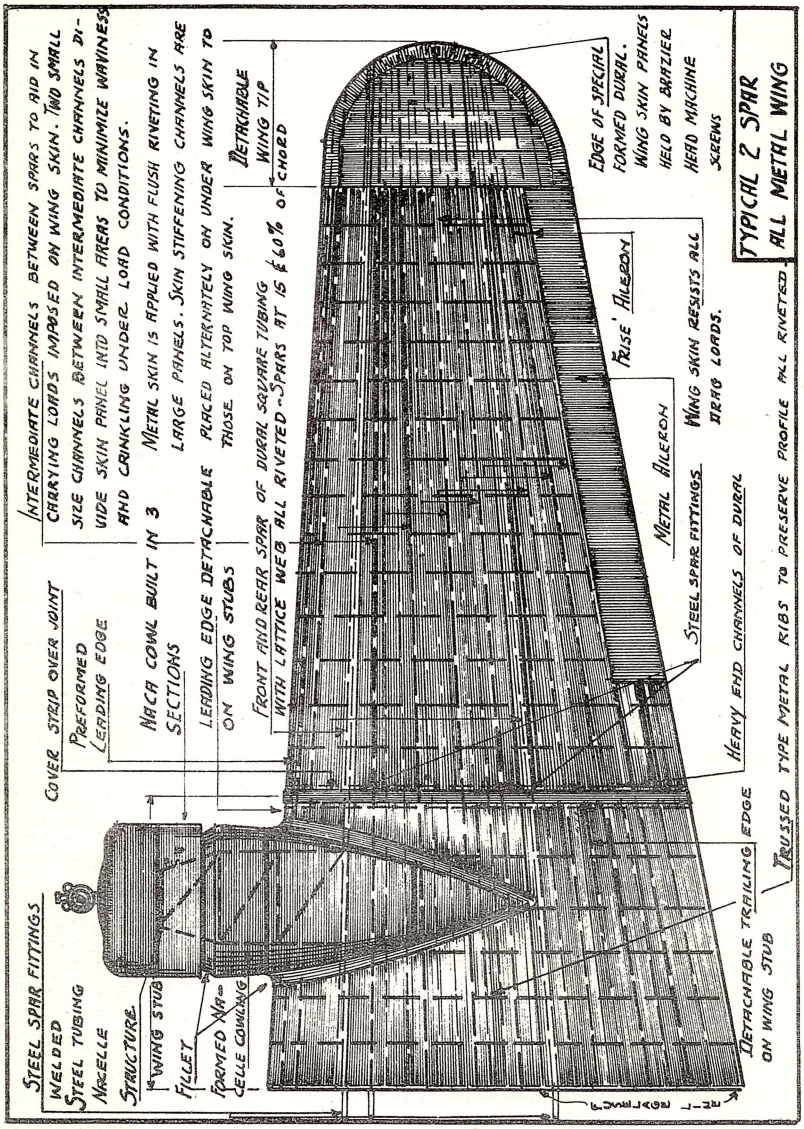
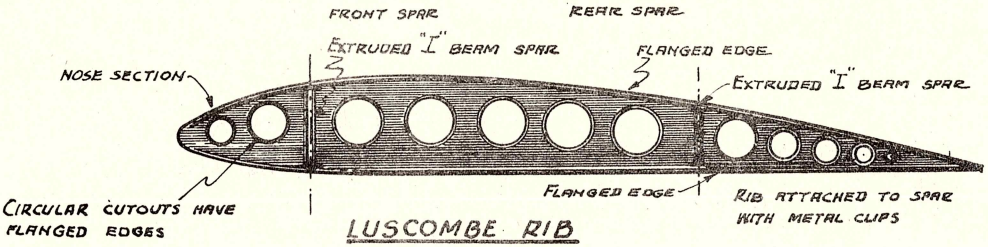
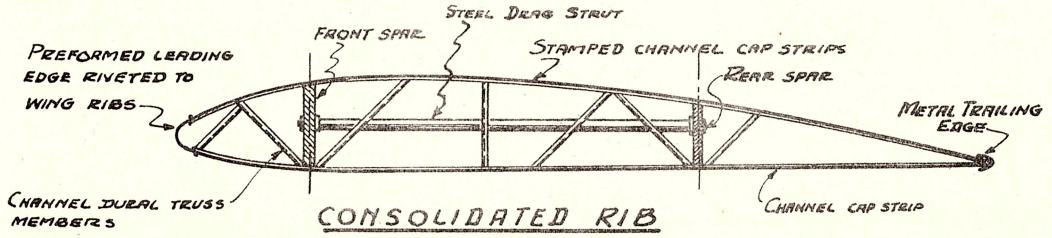

STEEL SPAR FITTINGS
WELDED
STEEL TUBING
NACELLE
STRUCTURE
1st WING STUB
FILLET
FORMED Nac=
ELLE COWLING
COVER STRIP OVER JOINT
PREFORMED
LEADING EDGE
NACA COWL BUILT IN 3
SECTIONS
LEADING EDGE DETACHABLE
ON WING STUBS
FRONT AND REAR SPAR OF DURAL SQUARE TUBING
WITH LATTICE WEB ALL RIVETED - SPARS AT 15 & 60% OF CHORD
INTERMEDIATE CHANNELS BETWEEN SPARS TO AID IN
CARRYING LOADS IMPOSED ON WING SKIN. TWO SMALL
SIZE CHANNELS BETWEEN INTERMEDIATE CHANNELS PR-
VIDE SKIN PANEL INTO SMALL AREAS TO MINIMIZE WAVINESS
AND CRINKLING UNDER LOAD CONDITIONS.
METAL SKIN IS APPLIED WITH FLUSH RIVETING IN
LARGE PANELS. SKIN STIFFENING CHANNELS ARE
PLACED ALTERNATELY ON UNDER WING SKIN TO
THOSE ON TOP WING SKIN.
DETACHABLE
WING TIP
EDGE OF SPECIAL
FORMED DURAL.
WING SKIN PANELS
HELD BY BRAZIER
HEAD MACHINE
SCREWS
RISE' AILERON
METAL AILERON
STEEL SPAR FITTINGS
WING SKIN RESISTS ALL
TRAD LOADS.
HEAVY END CHANNELS OF DURAL
DETACHABLE TRAILING EDGE
ON WING STUB
TRUSSED TYPE METAL RIBS TO PRESERVE PROFILE ALL RIVETED
TYPICAL 2 SPAR
ALL METAL WING

PLATE 16



LUSCOMBE RIB

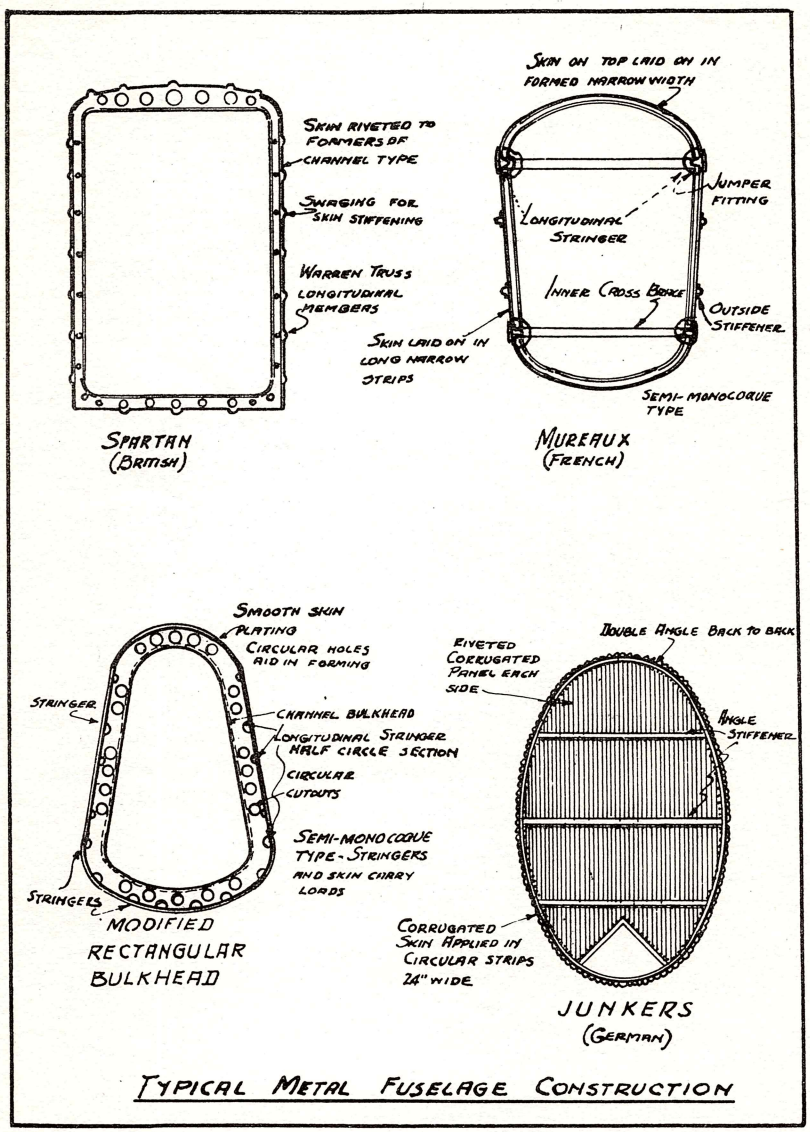
RIBS OF THIS TYPE MUST BE PRESSED FROM STRETCHER LEVELED STOCK. THE RIB FLANGES MUST BE FORMED WITHOUT TWISTING THE WEB. THIS RIB IS MADE IN ONE PIECE.



CONSOLIDATED RIB

THESE RIBS EMPLOY RIVETED CONSTRUCTION. THE SPAR ATTACHMENT TO THE WOOD SPAR IS THROUGH MEANS OF CEMENT COATED NAILS THROUGH THE CAP STRIPS. FABRIC IS ATTACHED TO RIB BY PARKER SCREWS. THE DRAG TRUSS USES A STEEL TUBE WITH SINGLE CROSSED DRAG WIRES. THESE RIBS ARE ASSEMBLED IN A JIG AND SLIPPED END WAYS ONTO THE SPARS.

PLATE 17



TYPICAL METAL FUSELAGE CONSTRUCTION

PLATE 18

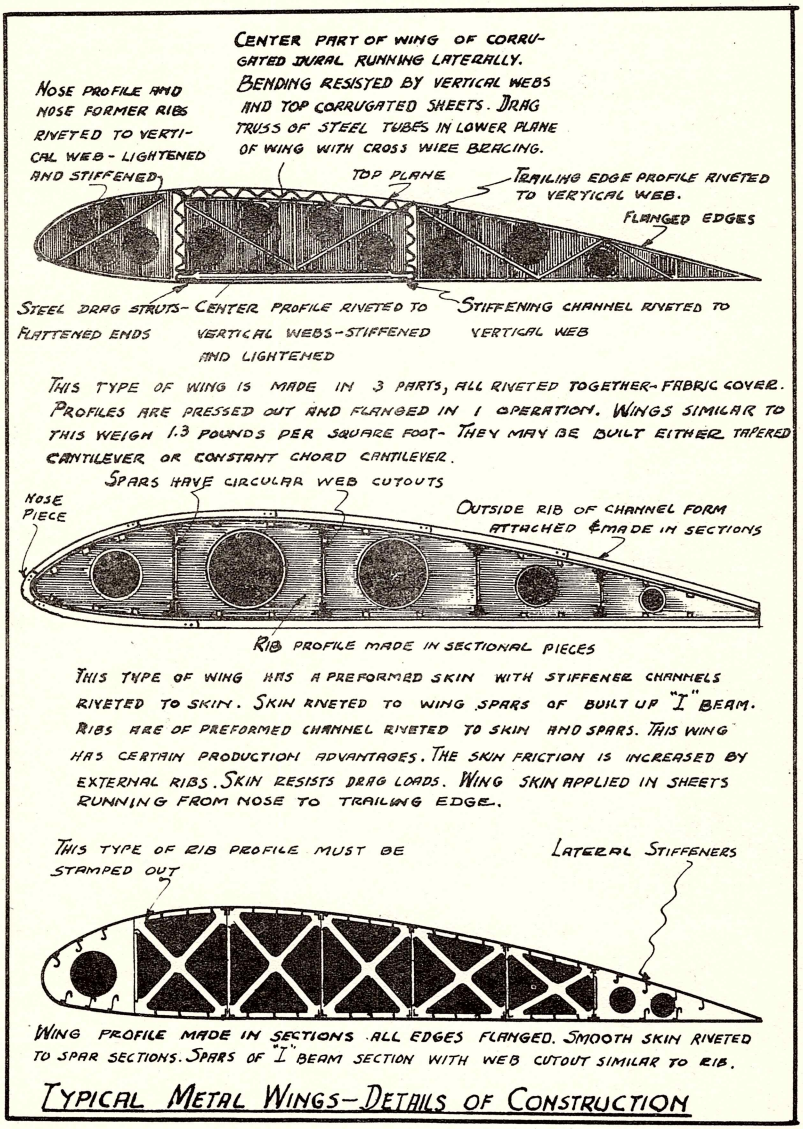
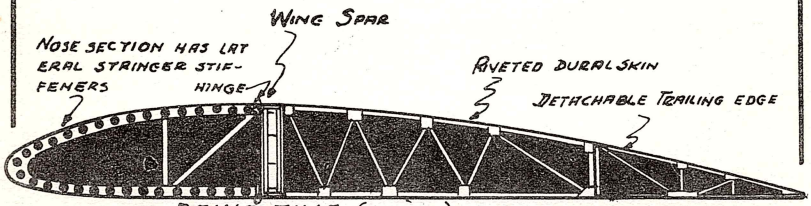
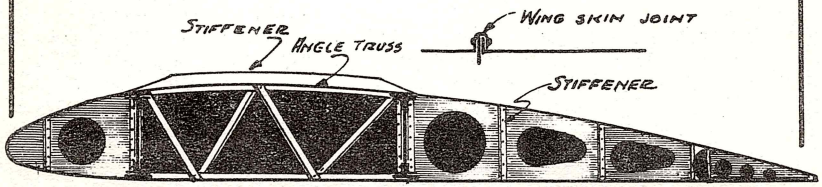

CENTER PART OF WING OF CORRUGATED DURAL RUNNING LATERALLY. BENDING RESISTED BY VERTICAL WEBS AND TOP CORRUGATED SHEETS. DRAG TRUSS OF STEEL TUBES IN LOWER PLANE OF WING WITH CROSS WIRE BRACING.
NOSE PROFILE AND NOSE FORMER RIBS RIVETED TO VERTICAL WEB - LIGHTENED AND STIFFENED
TOP PLANE
TRAILING EDGE PROFILE RIVETED TO VERTICAL WEB.
FLANGED EDGES
STEEL DRAG STRUTS - FLATTENED ENDS
CENTER PROFILE RIVETED TO VERTICAL WEBS - STIFFENED AND LIGHTENED
STIFFENING CHANNEL RIVETED TO VERTICAL WEB
THIS TYPE OF WING IS MADE IN 3 PARTS, ALL RIVETED TOGETHER - FABRIC COVER. PROFILES ARE PRESSED OUT AND FLANGED IN 1 OPERATION. WINGS SIMILAR TO THIS WEIGH 1.3 POUNDS PER SQUARE FOOT - THEY MAY BE BUILT EITHER TAPERED CANTILEVER OR CONSTANT CHORD CANTILEVER.
SPARS HAVE CIRCULAR WEB CUTOUTS
NOSE PIECE
OUTSIDE RIB OF CHANNEL FORM ATTACHED & MADE IN SECTIONS
RIB PROFILE MADE IN SECTIONAL PIECES
THIS TYPE OF WING HAS A PREFORMED SKIN WITH STIFFENER CHANNELS RIVETED TO SKIN. SKIN RIVETED TO WING SPARS OF BUILT UP "I" BEAM. RIBS ARE OF PREFORMED CHANNEL RIVETED TO SKIN AND SPARS. THIS WING HAS CERTAIN PRODUCTION ADVANTAGES. THE SKIN FRICTION IS INCREASED BY EXTERNAL RIBS. SKIN RESISTS DRAG LOADS. WING SKIN APPLIED IN SHEETS RUNNING FROM NOSE TO TRAILING EDGE.
THIS TYPE OF RIB PROFILE MUST BE STAMPED OUT
LATERAL STIFFENERS
WING PROFILE MADE IN SECTIONS ALL EDGES FLANGED. SMOOTH SKIN RIVETED TO SPAR SECTIONS. SPARS OF "I" BEAM SECTION WITH WEB CUTOUT SIMILAR TO RIB.
TYPICAL METAL WINGS—DETAILS OF CONSTRUCTION

PLATE 19



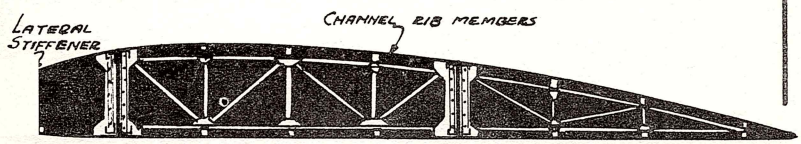
DEWOITINE (FRENCH)

THE NOSE SECTION IS DETACHABLE BY MEANS OF A PIANO HINGE. THE SPAR IS BUILT UP OF ELEMENTS OF DECREASING GAUGE FOR EQUAL STRESS. THE WEB IS OF WARREN TRUSS WITH FORMED MEMBERS RIVETED CONSTRUCTION. TORSION FORCES ARE RESISTED BY NOSE SECTION. SPAR CARRIES ONLY BENDING LOADS.



PAMSTOWE (POLISH)

SPAR IS BUILT OF EXTRUDED ANGLES AND A STIFFENED WEB. WING SKIN RIVETED ACROSS CHORD IN NARROW STRIPS. SPARS ARE TAPERED IN EVERY DIRECTION AND GAUGE FOR EQUAL STRESS. THE RIBS ARE BUILT IN FOUR SECTIONS. THE WING IS EXTERNALLY BRACED.

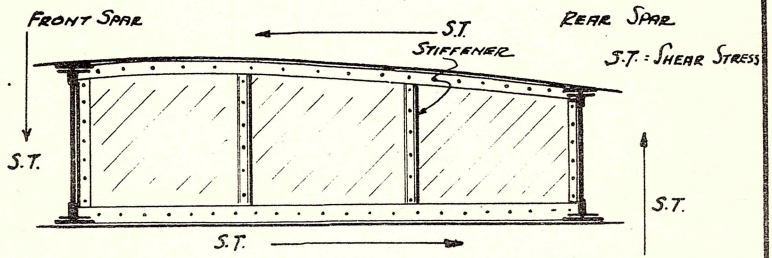


MUREAX (FRENCH)

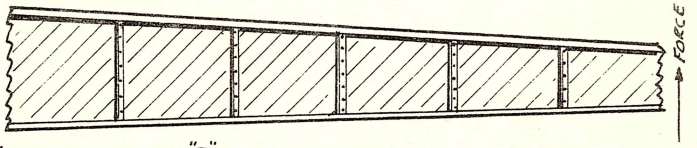
THE WING SKIN IS LAID IN NARROW WIDTH STRIPS ACROSS THE CHORD AND RIVETED TO CLIPS ATTACHED TO WING RIB. RIBS MADE OF RIVETED CHANNELS. WING HAS 2 SPARS OF A STAMPED WEB WITH CHANNEL TOP AND BOTTOM FLANGES. RIBS DO NOT EXTEND FULL DEPTH OF WING. SKIN IS CARRIED ON LATERAL CHANNEL STRINGERS. RIVETED WING SKIN JOINTS ARE OVERLAPPED.

TYPICAL WINGS

PLATE 20

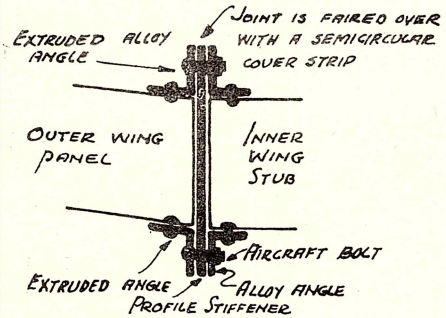


SHEAR STRESSES IN A BOX WING WITH FRONT AND REAR SPARS AND DRAG BRACES, IN A VERTICAL DIVE, ASSUMES THE LINES OF CRINKLING OF THE DRAG TRUSS WEB AS SHOWN ABOVE (MAXIMUM LOADING CONDITION)

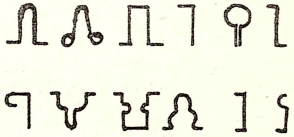


IN A BOX SPAR OR "I" BEAM SPAR UNDER BENDING FORCES CAUSES CRINKLING OF THE THIN GAUGE WEB AS SHOWN. THE STIFFENERS ARE NARROWER IN WIDTH WHERE SPAR IS STRONGEST. THE STIFFENERS STRENGHTNENS THE WEB ABOUT 20 GAUGE THICKNESSES ON EITHER SIDE IN DISTANCE ON THE WEB. THE WEB WILL FAIL BEFORE THE RIVETS WILL SHEAR.

TYPICAL EXAMPLE OF CRINKLING FAILURE



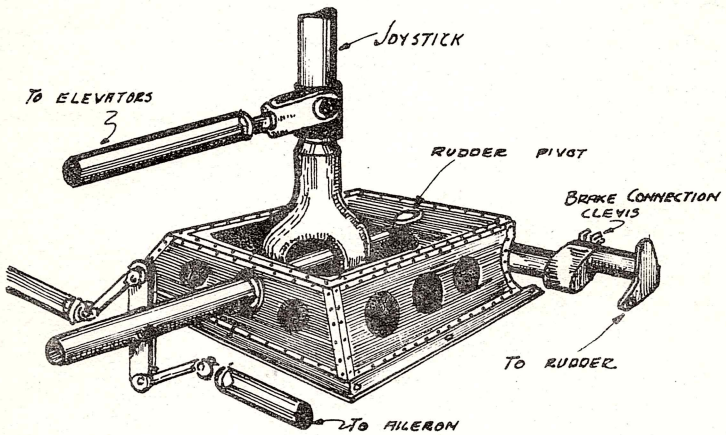
NORTHROP WING JOINT



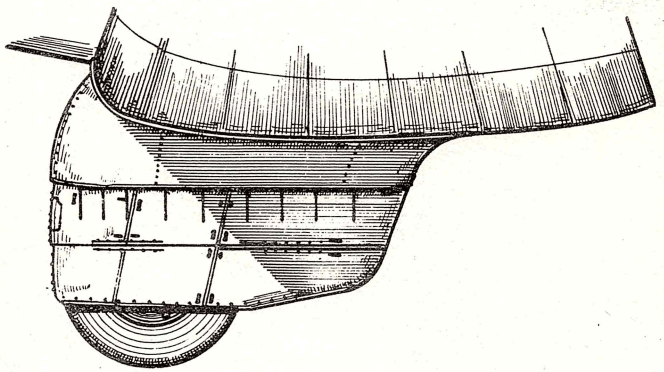
STRINGERS AND CAP STRIPS ARE USUALLY MADE FROM SHAPES SIMILAR TO THE ABOVE. THE SHAPE USED IS INFLUENCED BY COST, WEIGHT, STRENGTH, AND EASINESS TO MAKE IN PRODUCTION.

TYPICAL METAL DETAILS

PLATE 21



TYPICAL EXAMPLE OF DURAL CONTROL STICK MOUNTING



TYPICAL EXAMPLE OF LANDING GEAR FAIRING
(NORTHROP TYPE)

PLATE 22

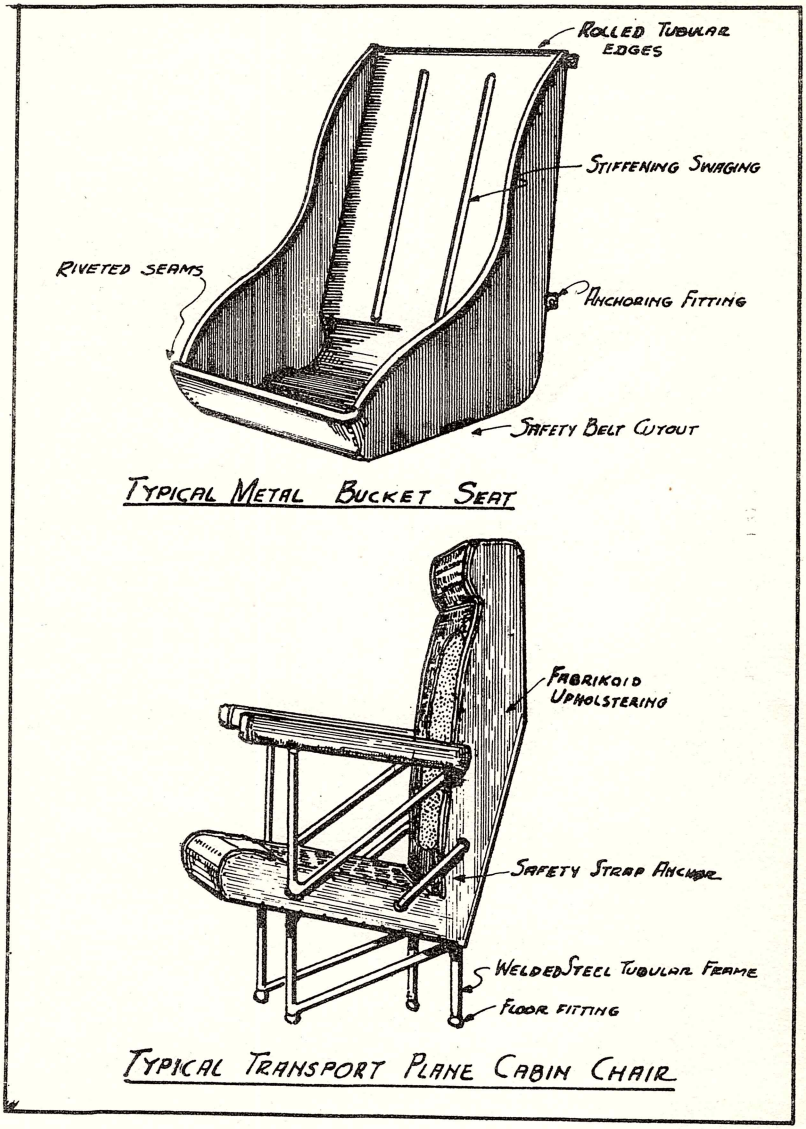

ROLLED TUBULAR EDGES
STIFFENING SWAGING
RIVETED SEAMS
ANCHORING FITTING
SAFETY BELT CUTOUT
TYPICAL METAL BUCKET SEAT
FABRIKOID UPHOLSTERING
SAFETY STRAP ANCHOR
WELDED STEEL TUBULAR FRAME
FLOOR FITTING
TYPICAL TRANSPORT PLANE CABIN CHAIR

PLATE 23

300